JOURNAL OF

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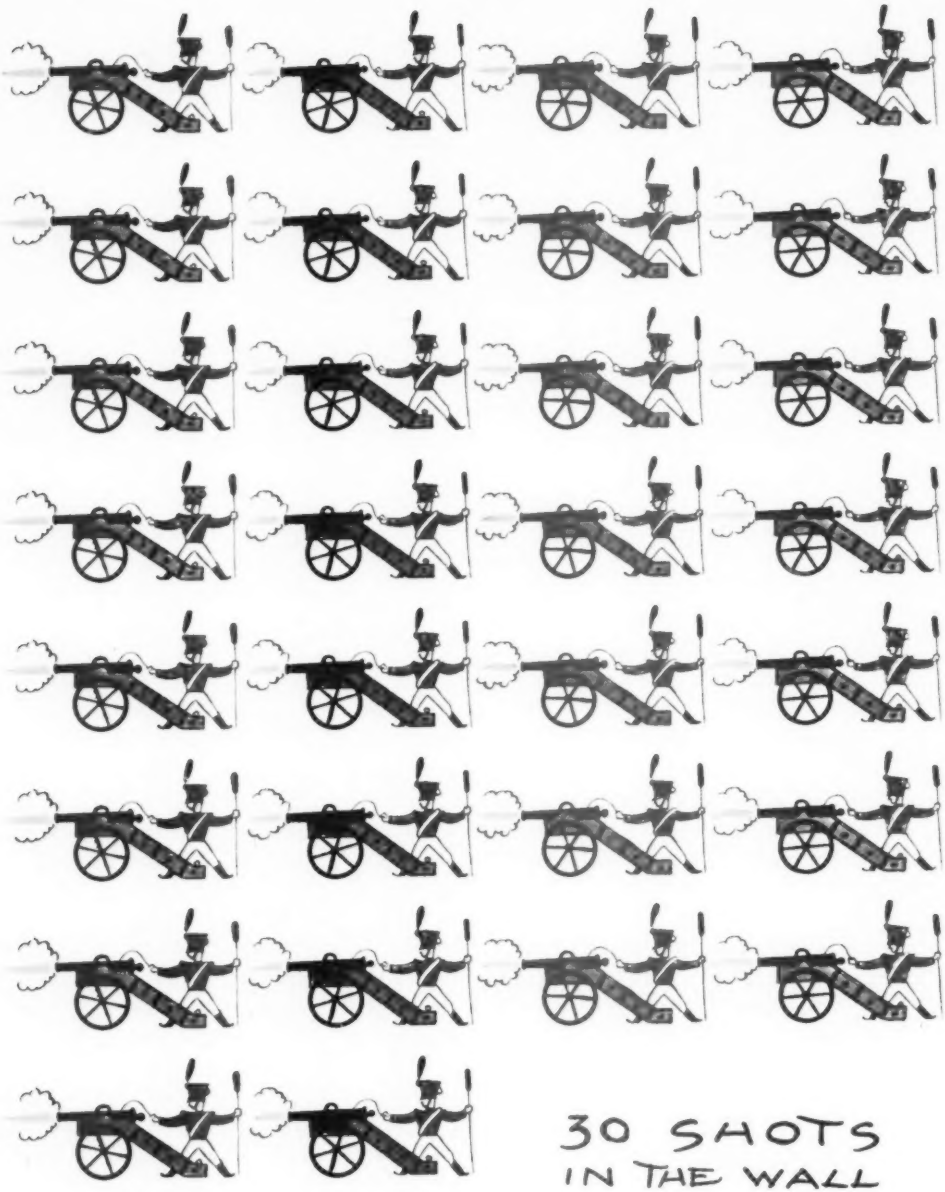
SEPTEMBER, 1952



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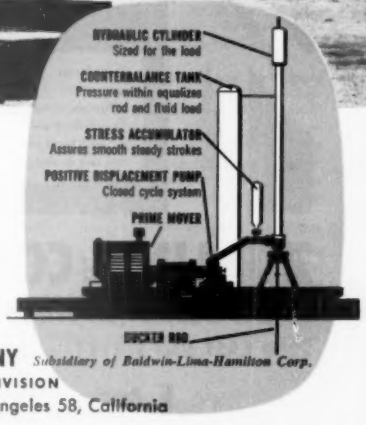

Here in a West Texas field is a typical installation of a PELTON Long Stroke Hydraulic Pumping Jack. This is the most modern, most efficient surface pumping unit ever devised for the sucker rod pumping of oil wells. With PELTON, each well may be pumped to its maximum potential and lifting costs reduced to the absolute minimum.

Hundreds of PELTON installations in Mid-continent and California fields have proved Long Stroke Hydraulic Pumping the most satisfactory method for pumping the deeper wells and the shallow wells with heavy production.

PELTON Jacks are available in seven models with polished rod load ratings from 20,000 to 40,000 lbs. Stroke lengths 10, 20 and 30 ft. The complete story on this modern and successful method of pumping is contained in PELTON'S new catalog.

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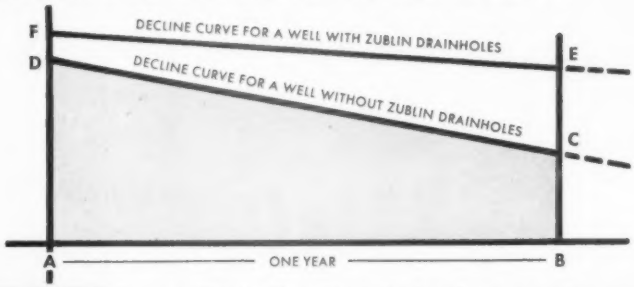

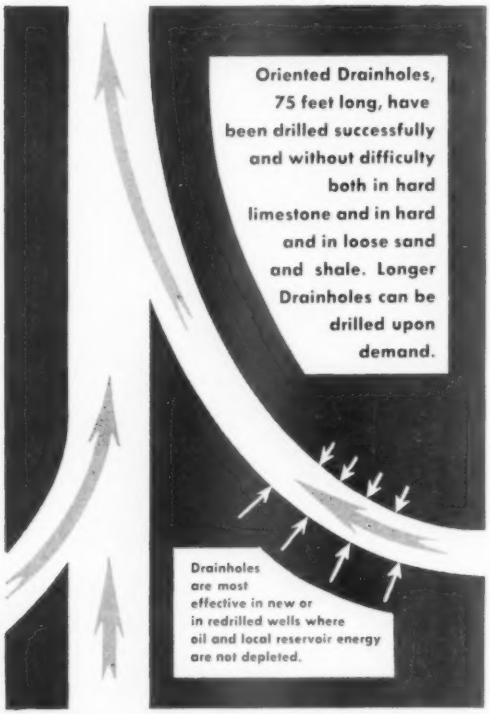
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Journal of Petroleum Technology

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On the Cover — The varied architectural forms of the Cities Service Refinery at Lake Charles, La., are highlighted during the night operations by safety flares and floodlights. In the foreground are high pressure storage spheres for butadiene and other highly volatile refinery products; behind them the glittering outlines of the catalytic crackers. On the left like three huge candles, the flare stacks burn off waste gases that might be hazardous in the processing area. *Photo courtesy Cities Service Co.*

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B and W LATCH-ON CENTRALIZER

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And proof is even more conclusive and timely, when, after perforating with other types of bullet perforators, McCullough recently perforated the same wells, with

production increases of: 6 B/D to 90 B/D; 0 B/D to 100 B/D; 60 B/D to 150 B/D; 30 B/D to 70 B/D; etc.

Add to this, burrless holes (produced by exclusive McCullough Burrless Bullets); exact spacing; the strongest gun body; and the fact that McCullough holds all world records for speed, efficiency and results. Factors contributing to —or the result of—deeper, cleaner holes, consistently.

Is it any wonder that McCullough Bullet Type Gun Perforators are the choice of leading oil operators, as evidenced by the fact that McCullough does most of the large perforating jobs.

Consistency means dependability.

Call Your McCullough Service Engineer today. He will explain the technical reasons for these remarkable results. Or, if you prefer, write for the McCullough Technical Bulletin 201 — do it TODAY!

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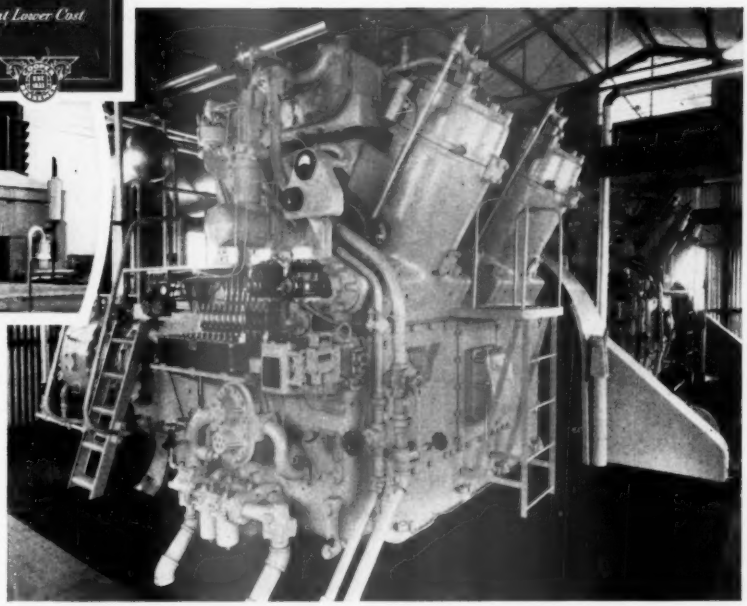
Another Example of Efficient Power at Lower Cost



These automatically controlled, 2-stage, 440 hp Cooper-Bessemer compressors take field gas at 20 psi and discharge at 425 psi into the pipe-line system of United Gas. Inset shows exterior of this new Universoil booster station in the West Beaumont field. Installation was handled jointly by Deerfield Petroleum, Inc., and Universal Petroleum Co., Oil Well Supply Co. furnishing all equipment.

RIGHT: Close-up of the operating ends of the modern GMV's from the crank-door side. Unusual flexibility makes these units ideal for automatic operation.

More profit in gas conservation...

...WITH GMV ONE-MAN AUTOMATIC OPERATION

WHEN a booster station practically runs itself, month in, month out, gas conservation is bound to be more practical, more profitable! And that's the success story behind those Cooper-Bessemer GMV V-Angles, shown opposite, in Universoil's new station in the West Beaumont field.

These two GMV's are daily handling 4,800,000 feet of gas that ordinarily would be flared—doing it efficiently *with the attention of one man for each 24 hours of operation!* It's a good example of the adaptability of modern Cooper-Bessemer V-Angles to extensive automatic control. The installation features variable speed governors to meet wide load variations, as well as automatic shutdown devices on the cooling water and lube oil systems. Likewise, the inlet scrubbers have low-liquid-level dump and shutdown controls.

If you're planning compressor jobs from 220 to 3,000 hp, automatically controlled or otherwise, check on Cooper-Bessemer V-Angles—today's and tomorrow's answer to compressor performance at its best.

The **Cooper-Bessemer** *Corporation*

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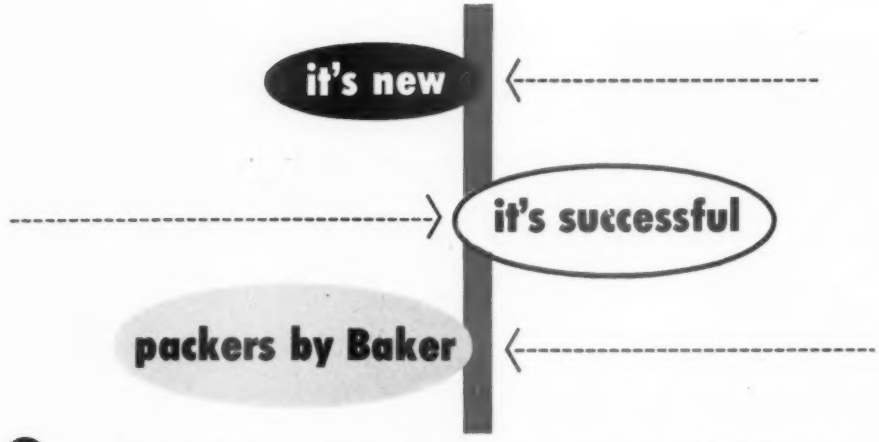

The Baker-Otis Selective DUAL-ZONE Production Hook-Up, which includes two Baker Retainer Production Packers, permits selective production (either pumping or flowing); acidizing, formation fracturing, and other treating; or testing of *either* zone through the tubing while simultaneously producing the *other* zone through the annulus. The switch in flow, or the selection of either zone for treatment is accomplished at the discretion of the operator, using a wire line, and it is not necessary to kill the well—to move or remove the tubing string—or to disturb the Baker Packer hook-up in any way.

COMPLETION ADVANTAGES

SAVES INSTALLATION TIME—You can perforate, set the Baker Packers, and complete the well by *simply running in the tubing*. Previously it has been necessary to make *at least two additional trips* with the tubing, killing the well each time.

SAVES EXPENSIVE DRILLING RIG TIME—After the Baker Packers have been set, the tubing run in, and surface connections made, the drilling rig can be moved off. All future work can be done with a swabbing unit and a pump truck—at distinct savings.

PROVIDES SAFETY IN HIGH-PRESSURE OR HYDROGEN SULPHIDE WELLS—Surface "flanging-up" is completed before the mud is displaced. After the mud has been displaced work is performed by using a wire line and wire line tools through a lubricator. This is a highly important advantage in high-pressure or hydrogen sulphide wells.

EITHER ZONE CAN BE TESTED WITHOUT REMOVING TUBING—Not only while the well is being completed, but at any time therafter, *either or both* of the zones can be tested *without removing the tubing string* or disturbing the packer hook-up installation.

ELIMINATES EXTRA ROUND TRIPS FOR ACIDIZING OR FORMATION FRACTURING—In the past, treatment of either or both zones has been carried out *before* the packers were set. This practice not only prolonged the completion by necessitating extra round trips, but subjected the zones to the full mud load during the interval between the completion of the treatment and the termination of the packer installation. The Baker-Otis Selective DUAL-ZONE Production Hook-Up, on the other hand, permits treatment of either or both zones at any pressure that is safe for the tubing, *at any time during the life of the well.*

PRODUCTION ADVANTAGES

PERMITS SWITCHING FLOW—Should the character of either zone change at *any future time*, the flow can be switched—even under pressure—by running in the appropriate Otis Choke on a measuring line.

PERMITS PLUGGING FLOODED ZONES—If either zone should load up or flood out, it can be plugged at the cross-over.

PERMITS SURFACE WORK WITHOUT KILLING THE WELL—If at any time it is necessary to overhaul the surface equipment, the annulus can be shut off at the cross-over. All needed work can then be done *without* killing the well.

GET YOUR COPY
of this new, three-color broadside which contains complete details of the Baker-Otis Hook-Up, with ordering instructions. Ask any Baker representative, or write the nearest Baker office.

BAKER OIL TOOLS, INC.

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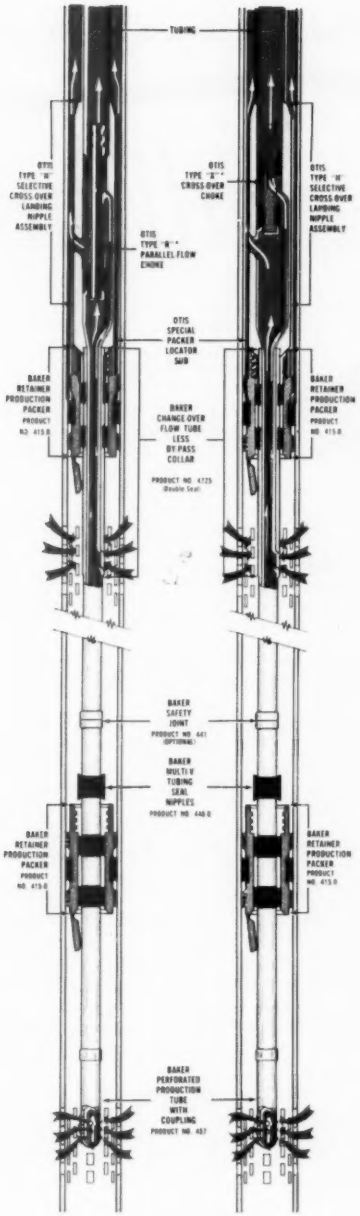
TUBING
OTIS TYPE "H" SELECTIVE CROSS OVER LANDING NIPPLE ASSEMBLY
OTIS TYPE "X" CROSS-OVER CHOKE
OTIS TYPE "H" SELECTIVE CROSS OVER LANDING NIPPLE ASSEMBLY
OTIS TYPE "R" PARALLEL FLOW CHOKE
OTIS SPECIAL PACKER LOCATOR SUB
BAKER RETAINER PRODUCTION PACKER PRODUCT NO. 413-B
BAKER CHANGE OVER FLOW TUBE LESS BY-PASS COLLAR
PRODUCT NO. 4725 (Double Seal)
BAKER RETAINER PRODUCTION PACKER PRODUCT NO. 413-B
BAKER SAFETY JOINT PRODUCT NO. 441 (OPTIONAL)
BAKER MULTI V TUBING SEAL NIPPLES PRODUCT NO. 440-B
BAKER RETAINER PRODUCTION PACKER PRODUCT NO. 413-B
BAKER RETAINER PRODUCTION PACKER PRODUCT NO. 413-B
BAKER PERFORATED PRODUCTION TUBE WITH COUPLING PRODUCT NO. 457

FIG. 1 FIG. 2

This is a simplified, schematic drawing.

HERE'S THE HOOK-UP THAT PROVIDES FLEXIBILITY, ECONOMY AND SUCCESSFUL RESULTS!

DESCRIPTION OF HOOK-UP

A standard Baker Two-Packer DUAL-ZONE Production Hook-Up with Change-Over Flow Tube, embodies a Special Locator Packer Sub which replaces the usual By-Pass Collar. The Locator Sub serves two purposes: (1) It connects the Outer Tube of the Change-Over Flow Tube with the Otis Type "H" Cross-Over Landing Assembly; and (2) It positions the Tubing Seal Nipples in the bore of each of the two Baker Packers.

Baker Retainer Production Packer

INSTALLATION AND OPERATION

After the Baker Packers are run and set (on wire line, tubing or drill pipe) the tubing string equipped with Baker-Otis components is run in. The well head equipment is then flanged-up, and the drilling rig replaced by a swabbing unit and a pump truck. It usually is preferable to seat the Locator Sub in the top packer before fluid-exchange operations are performed.

The appropriate chokes are then run in on a measuring line, located and locked in the Landing Nipple to permit the most advantageous flow arrangement for the initial completion, with both initial and future production possibilities in mind. At any future time the operator can switch the flow pattern merely by using a measuring line (under pressure) to retrieve the choke in use and replace it with the other choke.

LET *YOUR* BAKER REPRESENTATIVE CHECK YOUR NEEDS AND ADVISE YOU

Any Baker representative will gladly discuss your problems at the well; make specific recommendations; and arrange for installation of the Baker Packers and the Baker-Otis Hook-Up—Call him today.

Fig. 1—Parallel Flow

(Lower Zone through Tubing; Upper Zone through Annulus)

An Otis Type "X" Cross-Over Choke is run on a measuring line; seated in the landing nipple; and the upper zone swabbed-in through the tubing. The choke in use is then replaced with an Otis Type "R" Parallel Flow Choke, and the lower zone is swabbed-in.

Fig. 2—Cross-Over Flow

(Lower Zone through Annulus; Upper Zone through Tubing)

An Otis Type "R" Parallel Flow Choke is run in on a steel measuring line; seated in the landing nipple; and the lower zone swabbed-in. The choke in use is then replaced with an Otis Type "X" Cross-Over Choke and the upper zone is swabbed-in through the tubing.

There's more than acid to acidizing

Dowell Addition Agents

HELP SOLVE WELL PROBLEMS

Successful acidizing treatments demand more than just acid. Any well may present problems that call for special chemicals to be added to the acid. These *addition agents* can make the difference in the well's production.

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TO REDUCE SILICATE SWELLING—Ask for *Dowell XM Acid* . . . contains chemicals to speed well clean-up. It reduces swelling of silicates found in clay minerals, a problem often encountered in acidizing treatments.

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TO INCREASE PENETRATING ABILITY—Ask for *Dowell XF Acid* . . . contains surface tension reducing agents to increase penetrating ability of the acid. Aids return of spent acid and permits treatment of relatively fine pores.

TO REMOVE "GYP"—Ask for *Dowell XG Acid* . . . contains a foaming agent to use in removal of "gyp" from tubing or face of pay zones.

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FOR OIL INDUSTRY CHEMICAL SERVICE

Editorial

The Professional Concept

By Joe B. Alford
Executive Secretary
Petroleum Branch, AIME

A profession is not merely a group of men or women who possess in common certain knowledge and certain elaborate skills which they apply to specialized service for a good salary or an appropriate fee; it is a group of persons who have entered into a compact with each other to serve their mutual interests and the common good.

The above statement by the late William E. Wickenden in *A Professional Guide for Junior Engineers*[1] sets forth the qualifications and moral foundations upon which all professions rest. It has great import.

In the same publication, which should be read and in the library of every person aspiring to be an engineer, Wickenden stated further:

In its higher senses, a profession is an occupation which:

1. Renders a specialized service *based upon advanced specialized knowledge and skill, dealing with its problems primarily on an intellectual plane rather than on a physical or manual labor plane;*
2. Involves a confidential relationship *between a practitioner and a client or employer;*
3. Is charged with a substantial degree of public obligation, *by virtue of its possession of specialized knowledge;*
4. Enjoys a common heritage of knowledge, skill, and status *to the cumulative store of which professional men are bound to contribute through their individual and collective efforts;*
5. Performs its services to substantial degree in the general public interest, *receiving its compensation through limited fees rather than through direct profit from the improvements in goods, services, or knowledge which it accomplishes;*
6. Is bound by a distinctive ethical code *in its relationships with clients, colleagues, and the public.*

The most basic principle of professional responsibility is *trusteeship*, as a professional man is given a trust by those who employ his services. The trust arises from the great human needs — such as illness, legal protection, safety, and the conversion of raw material to useful products — in which people must rely on others who are skilled in satisfying these needs. The trust cannot be violated, because the profession is granted the right to exist in return for its services and the agreement that society will be held immune from exploitation.[2]

Petroleum Engineering is a Profession

The three traditional professions of law, medicine, and divinity had a common origin in the need of primitive peoples for government, health, and spiritual life. Such peoples did not need engineering until they began to move, to build, and to produce; as a consequence, the development of engineering into a profession came more slowly, occurring largely within the past 200 years. Although engineers are still struggling with "status" and "recognition," the professional standards for engineering as a whole have been highly developed, and a vast amount of scientific knowledge has been recorded as its foundation. It is a full grown profession, with a high degree of trusteeship.

Petroleum engineering has its rightful place as a branch of the larger field; it meets all of the requirements for a profession. From its inception in 1901 with the discovery of Spindletop and the activities of Captain Anthony F. Lucas, it has experienced a dynamic growth through the development of concepts, techniques, and practices to the present state of the art. It is a young, vigorous profession with a bright challenge in the future — what is unknown today about petroleum and its production is vast. It is a profession with a great trusteeship, for when the final story is told, it will be responsible for the production of a major part of this nation's supply of oil.

Professional Life is Twofold

Full professional life can not be achieved in isolation . . . some aspects of professional life are essentially individual, while some are essentially group relations.[3]

The *individual* aspects of professional life concern the man himself. He must perform his own work, take pride in it, and bear responsibility for it. The observance of a confidential relationship with his employer and the discharge of the public trust rests solely on him; the enhancement of his reputation rests upon his professional behavior.

The *collective* aspects are bound up with the group which engages in his particular profession. The collection of knowledge held by the group comes to him as a heritage from his affiliation with the group. He is obligated to add to that knowledge from his own experience; he must lend his support to the maintenance of the standards which the profession observes; and he must give part of his energy to the organization which serves the profession. In short, the profession has a *claim* on him; he must acknowledge it and do his part *to advance the art for the sake of the art itself.*

The Rewards

An awareness of the professional concept, and the practice of an art within its light, can bring rewards in numerous ways. These are perhaps intangible, imaginary, and even aesthetic. Yet, it is significant that many professional men, both young and old, will honestly say that such rewards mean more than those found under the sign of the dollar.

[1] Wickenden, W. E.: *A Professional Guide for Junior Engineers*, Engineers' Council for Professional Development, 29 West 39th St., New York, 37.
[2] Dueker, W. L.: "On Engineering and Professions," *Texas Professional Engineer*, (August, 1949) 3.
[3] Wickenden, W. E.: "The Second Mile," Address published by the Engineers Council for Professional Development, 4.

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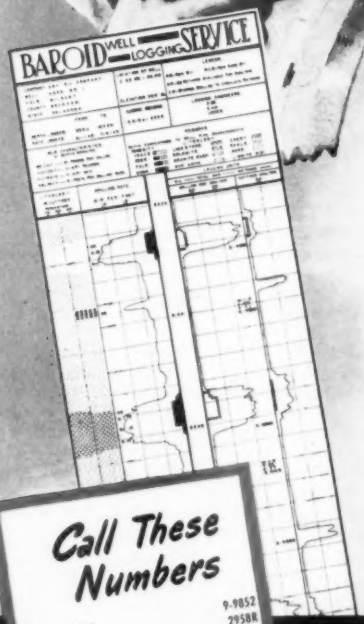

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Improved Production by Chemical Treatment In Gulf Coast Areas

By Burton Aulick, H. F. Hopkins, Frank Saye, Members AIME, and Wayne Hower
Halliburton Oil Well Cementing Co.

A method has been developed to restore permeability of certain sands containing bentonite which have been blocked by drilling fluid filtrate. Both older producing wells and initial completions have responded to the new treatment with increased production.

The oil and gas producing zones of the Gulf Coast areas are recognized as possessing relatively high natural permeability and reservoir pressure. In spite of these facts, many well completions are difficult and frequently disappointing as to initial potentials. Formation characteristics, as disclosed by electric well logs, cores and drill-stem tests, in many cases indicate potential production which is not developed upon completion of the well in the zone in question. Some such cases have been abandoned which, in view of presently known facts, could have been made into satisfactory producers.

Other wells which were originally successfully completed, but which later required remedial work of various kinds, frequently prove difficult or impossible to recomplete to the production efficiency existing before such work-over was performed. These cases lead to the belief that the production interference is a condition localized to the vicinity of the bore. Though it is not always possible correctly to analyze the cause for this effect, it is logical to assume that original efficiency might, at least in part, be recreated by relieving the local bore area of the matter responsible for the blocked condition.

Consideration of these facts has caused much thought on processes and techniques which might re-establish as much of the original permeability as possible. Many procedures for this purpose, which are successful in other oil producing areas, have not been particularly effective in the Gulf Coast zones.

In order to successfully attack the problems pertinent to this area, it is necessary to define the conditions and effects considered to exist. Generally, the recognized producing sands of the Gulf Coast area are known to contain varying quantities of bentonite of a type which readily absorbs and retains water which, in turn, creates a reduction of permeability due to swelling. The most prevalent source of water which can create this condition is filtrate from drilling fluid. Recent findings,[1,2] have shown that drilling fluids can penetrate appreciable distances into sands. Studies have disclosed that excessive pressures created during drilling period and running of casing often force large quantities of drilling fluids into the formation. During remedial operations, fresh water is often forced into the sand in the vicinity of the bore. Instances are of record where sand or gravel placed opposite the producing zone by use of salt water has blocked reservoir flow at the conclusion of the gravel packing operations.

End effects are often noticed where formation fines and interstitial water accumulate, over long period of production, in the formation adjacent to the well bore which act to reduce the permeability to oil and may greatly reduce the production of the well.

It is possible for oil and water emulsions to be formed within a producing formation near a well bore. Where such is the case, oil production will usually be reduced because of blocking set up by the ordinarily higher viscosity and thixtropic property of the emulsion.

The question naturally arises as to what can be done as a corrective measure to alleviate these blocking conditions. The ideal situation would be to restore the sand to its original condition existing prior to penetration by the drill. In the line of attack to this problem, it seemed logical that the blocking materials should be removed from the formation, and those which could not be entirely removed, be so altered that their blocking action would be reduced to the fullest possible extent.

Several ideas for accomplishing removal of the blocking causes were considered. Of these, all were abandoned for reasons of practicality in favor of a chemical method; this being the application of chemical agents designed to reduce size of bentonite particles, disperse muds, break water blocking, and reduce emulsions in the vicinity of the well bore.

Realizing that actual dissolving of silicious and bentonitic materials could not be achieved in appreciable amounts under well treatment conditions, it was apparent that other physical changes of benefit might be created to increase permeability by removing restrictions to flow.

LABORATORY WORK AND THEORY

It was discovered in the laboratory that a chemical treatment utilizing a weak solution of hydrochloric acid coupled with certain aromatic sulfonic acids could be highly beneficial in increasing effective permeability of sands containing bentonite.

The swelling or water adsorption properties of bentonite depend on the nature of the surface of the individual particles. This may further be broken down to include the metal (cation) ion or ions that are present as well as the electrical charges surrounding the bentonite particles.

It has been stated that an expanding bentonite can be changed to a non-expanding bentonite by merely changing the

[1]References given at end of paper.
Paper to be presented at Houston meeting, Oct. 1-3, 1952.

outer or exchangeable cations. This statement, undoubtedly, has merit and is backed by the work of Baver and Winterhorn[1] in their study concerning the water adsorption properties of various bentonites. Their findings definitely show that different metal salts of the same bentonite caused a drastic change in the amount of water that could be adsorbed and tightly held. Listed below are three metal bentonites and the amount of water that one gram of the bentonite will adsorb:

Sodium bentonite	11.08 cu cm
Calcium bentonite	2.50 cu cm
Hydrogen bentonite	2.20 cu cm

The above ratios cannot be expected to be exactly the same for all of the great variety of bentonite, but the trend is definite.

The electrical charge of a bentonite particle further governs the amount of water that can be adsorbed under any given set of conditions. It has been stated that the electrical charge[4] on bentonite is 8×10^{12} electrons per sq cm, and that some bentonites have a surface area of as much as 330 sq meters per gram. This powerful charge can be partially neutralized by the presence of metal salts in the water surrounding the bentonite, and thus prevent normal adsorption and swelling. This swelling is well known in the oil industry and has been illustrated many times in respect to the comparative action of some shales in fresh and salt water.

Further evidence has shown that complex ions and even anions can be absorbed on the bentonite surfaces. The introduction of this phase further complicates an already complex subject, but it is an important factor that should be kept in mind where bentonite is, or may come, in contact with oil.

The chemical mixture of dilute hydrochloric acid and aromatic sulfonic acid has a powerful effect on the surface characteristics of bentonite. The hydrogen ion from the hydrochloric acid will replace the predominant sodium ion, thus causing the formation of hydrogen bentonite. Such a change will cause the former swollen bentonite particle to lose most of its affinity for water. The system, bentonite and water, will be reduced in size, and free water will be released from each nucleus. A partial neutralization of the electrical charges will also be noticed. This will be due to the excess of hydrochloric acid plus the salt formed by the ion exchange reaction.

The use of the aromatic sulfonic acids in this chemical mixture causes several actions to be added to the phenomenon of ion exchange. The aromatic sulfonic acid is a very potent surfactant and emulsion breaker. The recommended proportion of the above chemical mixture has a low surface tension that falls in the range of 33.6 dynes per cm at 78°F.

Such a mixture will penetrate mud filter cakes and bentonitic sand formations effectively, and thus contact a great quantity of bentonite. The efficiency of the ion exchange is undoubtedly increased by this action, and the released water, having a low surface tension, along with the original solution, is easily recovered from the treated horizon.

Where a quantity of mud has been lost to an oil-bearing formation, or the aim is to remove the mud filter cake from the sides of the well bore, the dispersing properties of this chemical mixture are highly important. The mud filter cake is not hardened by the ion exchange, but becomes dispersed as the exchange takes place, thus forming a fluid mixture very easily removed from the formation and the well bore.

The chemical mixture also has the property of breaking oil and water emulsions. Strong evidence has been obtained which indicates the presence of emulsions in oil-bearing formations, particularly where drilling mud is present. The solids in the drilling mud are excellent emulsion stabilizers which cause the formation of emulsions that can efficiently block the flow of oil to the well bore. Therefore, the breaking of these emulsions, and the recovery of the mud and water, is an essential factor that must be considered in the treatment of a formation to re-establish sufficient permeability for the economic production of oil.

The surface of the bentonite particle can be considered polar, due to the distance between the electrical charges on its surface. The surfactant in this chemical combination is also very polar and can be considered anionic in nature. In conjunction, a theoretical consideration pointed to the strong possibility of an adsorption of this complex ion on the surface of the bentonite particles. Laboratory tests have proven this theoretical concept, plus the fact that the same ion is strongly adsorbed on the sand grains. This adsorption aids the effort to change the nature of the surface of the bentonite particle, and thus alter its swelling and wettability in different environments. While it is possible for the surfactant to be leached from the sand grains, if subjected to the flow of water, tests have shown that large volumes of water are necessary to remove any high percentage of the adsorbed chemical from the solids, thus conclusively proving that a large volume of water or mud will develop a low surface tension as it passes through the treated sand body.

The effectiveness of the mixture of these chemicals on the permeability of bentonitic sands has been thoroughly investigated in the laboratory. A system was devised that simulated an oil well where fluids could be forced through the sand body in different directions, so as to determine relative flow rates of oil under a variety of conditions. A clean sand was contaminated with different proportions of a good grade of drilling mud bentonite and packed into the apparatus. The synthetic formation was then wet with fresh water and permitted to remain in a static condition until the bentonite was thoroughly hydrated. The flow of oil was reversed through the sand body until a constant flow rate was obtained. The chemical mixture was then forced into the sand body from the same direction as was the fresh water. The flow of oil was again reversed and a constant flow rate obtained. Similar tests were performed using dilute hydrochloric acid without the addition of the aromatic sulfonic acid, and the results are included for comparative purposes.

Per Cent Bentonite in Sand	Treating Agent	Percentage Increase in Oil Flow
10	Chemical Mixture	667
10	Dilute Hydrochloric Acid	300
20	Chemical Mixture	3,450
20	Dilute Hydrochloric Acid	1,538

A more striking difference in flow rate increases was noticed when similar sand bodies were treated with both agents, but no initial oil flow rate was determined before the chemical treatment. The conditions of the tests were very closely controlled to give the same density of sand and constant pressures were observed. An increase in oil flow rate, as compared to initial rates of previous determinations, as a result of the chemical mixture treatment of 3,445 per cent was obtained. A treatment with dilute hydrochloric acid under the same conditions showed an increase in the rate of flow of oil of only 161 per cent, thus substantiating the role played by the aromatic sulfonic acid in the chemical mixture.

A portion of the 119.2 bbl per ton bentonite used in the above tests was treated with the chemical mixture, washed, filtered, dried and reground. The yield of the bentonite thus treated was then only 35.7 bbl per ton. It appears that the surface characteristics of the bentonite particles were radically

changed, thus causing the swelling and water adsorption properties to be greatly altered.

Some interesting phenomena were observed during the above tests which are thought to be of value and are here listed for further reference.

1. Fresh water was never recovered when oil was forced through the sand body during the initial oil flow rate determinations.
2. Acid water, having a low surface tension, was recovered ahead of the oil on every test where the chemical mixture was used.
3. No bentonite was recovered with the oil on any of the determinations. Therefore, the great increase in permeability shown by the additional flow of oil is due to the change in the surface characteristics of the bentonite particles which caused the release of some of the previously very strongly adsorbed water.

METHODS OF APPLICATION

Applied to either an initial completion, or to an established well to improve production, the well treatment is usually a quite simple procedure. Volumes of the chemical solution are comparatively small, in general, 500 to 1,000 gal per stage, and injection pressures, as a rule, are rather low.

On new wells, after obtaining the initial production results, by whatever mechanical arrangement is appropriate to the area, the chemical treatment is then applied. This is ordinarily done through the regular well head connections, and the sub-surface equipment already in the well. For example, if a production packer is in place with mud fluid in the annulus above it, the treating solution is pumped straight into the tubing, thence into the formation against existing well pressures. This fluid is displaced to bottom and into the zone with sufficient following fluid, usually either oil or salt water, to force the chemicals out into the zone being treated, and leave the perforated or open hole section just covered with the treating solution.

It is not necessary for the chemical mixture to remain in place in a static state for more than a matter of minutes. One hour closed in is the general rule. Recompletion can then immediately follow. If natural flow will occur on opening the well, it is only necessary to run the recovery to pits until clean production is obtained. If well conditions are such that swabbing is permissible or necessary, the early clean up can frequently be speeded up by such practice as soon as the static closed in period is over.

Where the treatment is applied to older producing wells, the methods are also simple. Treatments have been applied through open ended tubing, through tubing with rods in place, and where conditions demand, through use of several varieties of well servicing tools and packers.

In wildcat wells which have shown very little recovery of oil and gas and large quanties of mud on test, these treatments have been applied directly through the drill stem testing assembly. Following such injection, the test proceeds with either flow or swabbing. Several such instances have resulted in good completions in zones which otherwise would have been plugged off.

Gallonage of the chemical solution to be applied has been the subject of much laboratory and field study. It is a practical impossibility to make a concise statement to cover all cases. The extremely varied conditions existing between fields, zones, and wells in them, make individual study a necessity. Some general rules can be stated which may be modified and adjusted as may be warranted by actual experience.

Five hundred gal of solution represents a practical minimum quantity for regular use. It is considered good practice, and experience verifies the idea, that it is better to run successive lots of this amount, than one large injection at one time. Again, this practice can, and should, be modified as actual well conditions may indicate.

In a new completion where there is evidence of large amounts of mud having been displaced into the sand to considerable distance from the bore, then the use of successive small gallonage treatments appears to be the practical approach; the thought being that less possibility would exist of pushing the mud in place further out into the zone, than if all the treating solution was injected at one time. If small lots are used, and the zone cleared between injections, better cleaning seems to result in this instance.

Where existing producing wells are to be treated, the gallonage and injection procedure may frequently be altered with resulting economic advantages. Here it may be possible to use a single stage injection of large size, rather than the successive stage method, and so gain in work time. Numerous cases are on record where a 1,000 gal treatment resulted in much more production increase than a 500 gal one. These results were entirely disproportionate to the ratio of treating volumes used. Probably the best approach, to the already producing well problem in a given field and zone, is to try first the smaller volume one-time treatment and ascertain the result, then progress to the larger type job and so make a comparison. Field results have been good with both methods, and only a direct comparison can show the better procedure in any field.

It is obvious that thickness and porosity of the zone being treated will influence the quantity of treating solution to be used. The foregoing statements refer to Gulf Coast sands which seldom have an effective thickness of more than 20 ft.

FIELD RESULTS

Field results have been encouraging in using this chemical treatment as a production stimulant. From Jan. 1, 1952, until Sept. 1, 1952, in excess of 200 wells have been treated in the Gulf Coast area with varying amounts of chemical. Many of these treatments have resulted in producing wells which would have otherwise been abandoned.

It is difficult to state with certainty the degree of success of these treatments. This is influenced by a large number of treatments attempted in a last stand effort to secure production. Many such treatments naturally did not produce successful results, and these zones were then abandoned. Conversely, however, there have been many instances of this treatment which did secure production. These have been sufficient in number to the extent that they have influenced the well owners in making decisions concerning any possibility of success in certain zones.

In South Louisiana results obtained include the following: In the Sparta production of the Opelousas field, four wells with an actual collective 24-hour test flow of 24,450 Mcf gas and 704 bbl distillate were increased by this treatment to 76,000 Mcf gas and 1,200 bbl distillate.

A Miocene well perforated from 9,508 to 9,517 had produced approximately 10,000 bbl of oil, and then ceased production

entirely. After repeated efforts to re-establish production by various means, this well was given a 500 gal chemical treatment. Production began immediately, and slowly increased to a settled rate of 80 B/D on 6/64 in. choke at a date one month after treatment.

Another Miocene well at 9,926 to 9,946 refused to produce at all on attempted initial completion. Fluid was swabbed down to 7,500 ft. Zone was next oil-squeezed and swabbed down several times, but fill-up never came higher than the 1,800 ft level. One thousand gal of the chemical treating solution were injected. The well responded with natural flow, no swabbing required, and established production of 200 B/D on $\frac{1}{8}$-in. choke.

Six interesting jobs were done in Charenton area at approximately 6,600 ft on old producers. One well producing 98 per cent water, 25 B/D net, was squeeze cemented, chemically treated and recompleted for 182 B/D, no water. Three wells were not producing at all. After treatment, production of 48, 40 and 100 B/D respectively, was obtained. Another well producing at 70 B/D was increased to 121 B/D. Still another producing at 8 B/D increased to 148 B/D. Each of these wells were treated with 500 gal in a single stage treatment. This group of six wells shows a cumulative net increase in production of 536 B/D.

In the University field, one well prospecting a zone which had up to that time in all previous attempts refused to produce, was treated with 1,000 gal. The well responded with a natural flow of 80 B/D, and an erratic water production, ranging from 0 to 10 per cent of total fluid. From the best information obtainable, this was the first production ever obtained from this particular sand, although the sand is well known, and shows for producing possibility on electric logs.

An interesting job was done in the Evangeline field on a well that had not produced any oil in a considerable period of time. This 6,700-ft well was treated with 750 gal and recompleted with natural flow of 85 B/D, and did not require swabbing. This declined over a period of six weeks to its present producing rate of 50 B/D.

In South Texas (Houston area) successful treatments have been performed in the Cockfield and Frio sections. These have been on both new and old wells. A Frio well in the Hastings field completed in 1937 for an original potential of 500 B/D had ceased producing entirely. In June, 1952, the well was given a 750-gal treatment. Recompletion resulted in 178 B/D flowing production.

In the Conroe field several successful treatments have been performed. One of these wells producing no oil and reported ready for abandonment, on treatment with 1,000 gal established a potential of 189 B/D flowing. This treatment was performed in April, 1952, and it is reported that this well still easily makes its allowable of 71 B/D by natural flow.

Another Conroe well approximately seven years old, making 38 B/D and 12 bbl water per day, was treated with 1,000 gal. After treatment this well had a potential of 98 B/D and produces at its allowable of 47 B/D.

A well in the Frio sand of the Magnet field responded to a 500-gal treatment by an increase in production from 9 B/D to 41 B/D.

Another Frio well, which had ceased to produce any oil, but would make 100 bbl of water per day, flowed 110 B/D and 42 bbl of water on test after having been treated with 1,000 gal. This was then reduced to the field allowable of 37½ bbl of oil, which was accompanied by 12 bbl of water. In this same vicinity, a well was producing 9 B/D by gas lift. A 750-gal treatment increased the production to 61 B/D flowing on 7/64-in. choke.

A 2,600-ft well in the Blue Ridge field making 14 B/D responded to a 500-gal treatment with an increase up to 42 B/D.

A Miocene producer, bottomed at 2,293 ft, in the West Columbia field, which was pumping 35 B/D, used a 1,000-gal treatment, which increased the production to 80 B/D.

In Southwest Texas (Corpus Christi area) there have been several instances in which this chemical treatment was of great assistance in effecting a satisfactory initial completion of a well. On some wells, drill stem tests previous to setting of casing and perforating showed commercial production to be obtainable. After perforations and subsequent testing, considerable amounts of mud were recovered on these tests, but no commercial production. Swabbing operations recovered only mud, gas and oil cut. In all instances where these conditions existed, and the chemical treatment then was applied, the condition was remedied to the extent that the mud block was destroyed and production obtained without further perforating or swabbing. These relatively few jobs indicate that if adopted as a completion practice, which some operators have already done, that production may be obtained easier and more economically, than by previously used methods in sections susceptible to mud or filtrate invasion.

CONCLUSION

The unique chemical combination of dilute hydrochloric acid and an organic material, aromatic sulfonic acid, has a marked effect in the reduction of water-swollen bentonite. Research in the laboratory disclosed that this chemical mixture could be used to improve the permeability to oil and gas of sands containing bentonite, either naturally in place or introduced as by drilling fluids.

Field applications on over 200 wells since Jan. 1, 1952, have resulted in a large number of successful instances for improving production, and in assisting initial completions. The oil and gas-bearing sands of the Gulf Coast area generally contain bentonite, and are susceptible to damage by fresh water as from mud filtrates and remedial work. Both older producing wells and initial completions have responded to this chemical treatment with stimulated production. This new chemical treating method has already shown encouraging results toward extending economic producing life of Gulf Coast wells. Because of the simplicity of application, it is possible that it may have an important effect in developing new production and extending old production in sands to which it is applicable.

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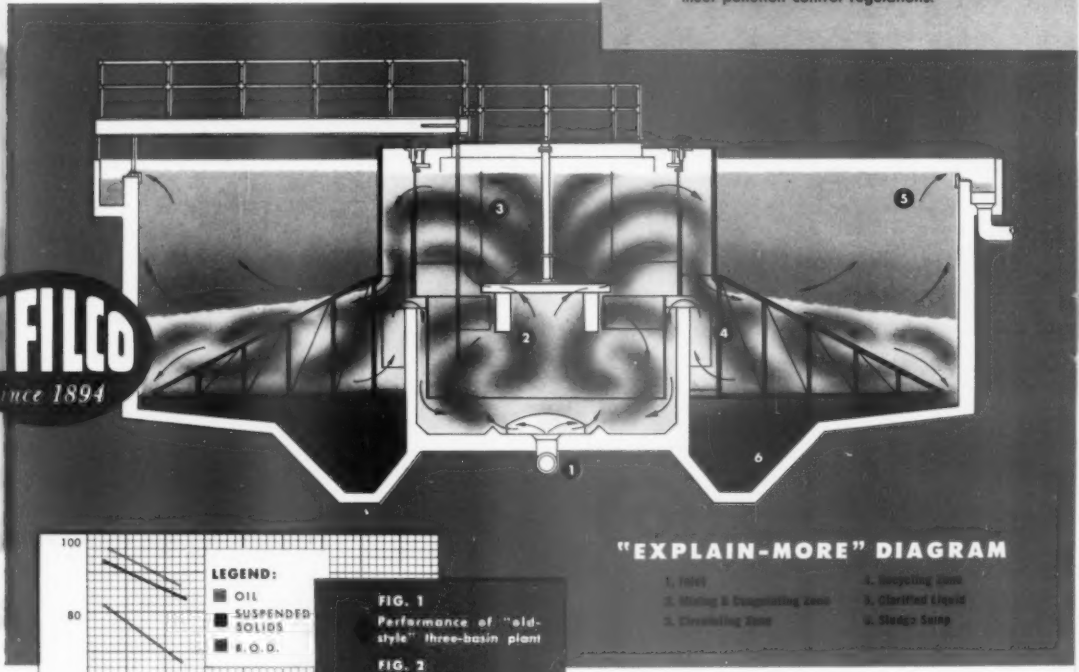

"EXPLAIN-MORE" DIAGRAM

1. Inlet
2. Mixing & Coagulating Zone
3. Clarifying Zone
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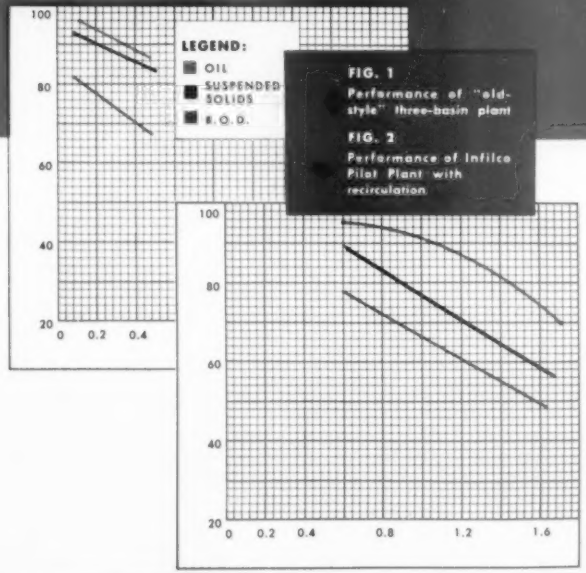

FIG. 1 Performance of "old-style" three-basin plant

FIG. 2 Performance of Infilco Pilot Plant with recirculation

TAKE A LOOK AT PROCESS SAVINGS—

Here's a recent pilot plant study. An Infilco pilot plant was installed in parallel with a treatment plant with separate mixing, flocculating and sedimentation basins.

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Methods of Electric Logging

Reported by J. A. Klotz
Pacific Technology Forum

Loy M. Charter, area logging engineer for the Shell Oil Co. presented the fourth talk of a series on "Elements of Petroleum Production" sponsored by the Pacific Technology Forum for the benefit of engineers in the Los Angeles area. Charter discussed well logging; future talks will be about reservoir fluids, fluid mechanics, solution gas drive, gravity drainage, natural water drive, and condensate production.

Charter limited his talk to a discussion of the objectives and methods of electric logging, but for maximum information, electric logging should be used in conjunction with other logging methods: core analysis, mud and chip logging, drilling rate records, and formation tests. Without aid from these other methods, however, the electric log can be used (1) to correlate stratigraphy between adjacent wells, (2) to show depths of sand and shale layers within a well, and (3) to indicate fluid content of sub-surface rocks. Charter explained the use of two electric logs, the resistivity log and the self-potential log, to determine the properties and saturations of subsurface fluids. Fluid property determination depends on the presence of salt water in the rocks penetrated by the well. If this water is relatively fresh, so that its conductivity is low, estimates of water saturation are not as reliable as they would be if the water were relatively salty. The resistivity log is a function of rock porosity, shape of pore channels within the rock, and water saturation, as well as water resistivity. The self-potential log is a function of changes in rock from sand to shale, difference in salinity between the fresh water drilling mud and the saline formation water, and of a filtration or streaming potential caused by mud filtrate flowing through the filter cake.

Self-Potential Log

Part of the self-potential, SP_e, results from an electrochemical cell that is formed at the junctions between fresh water mud, sand saturated with salt water, and shale saturated with salt water. Positive and negative ions from the saline formation water diffuse into the fresh water drilling fluid. Because shale is more permeable to positive ions than to negative ions, positive ions collect at the shale-mud boundary; this boundary becomes electrically positive with respect to the sand-mud boundary. The electrical potential that this sand-shale-mud concentration cell creates depends on the same variables that control other electrochemical cells. Among these variables are the relative mobility of positive and negative ions through shale, the conductivity of the salt water saturated sand, the difference in salinity between formation water and mud water, and the kinds of ions in the formation water and in the mud water. Most self-potential formulas have been developed for sodium chloride brines; if formation water contains a high concentration of other salts, serious error may result if these formulas are used without alteration. Electrochemical self-potential, SP_e, may be related to the resistivities of mud and formation water by the following equation:

$$SP_e = K \log_{10} (R_{mud}/R_{wtr});$$

K usually lies between 60 and 90.

Another part of the self-potential, SP_f, is caused by unequal transport of positive and negative ions by mud filtrate as it flows through the filter cake into the formation. Colloid chemists have named this potential "streaming potential"; it depends on the rate of flow of filtrate (therefore, on viscosity of the filtrate, permeability of mud cake, and filtration pressure difference) and on the electrical conductivity of the filtrate. Most of these are constant for a particular mud so that SP_f is proportional to filtration pressure:

$$SP_f = \triangle P \cdot sp_f,$$

where sp_f is specific filtration self-potential, a property of the drilling fluid.

Formation water salinity can be determined from the self-potential log by the following method. (1) Find a reliable portion of the SP curve; that is, a long flat SP maximum. This long maximum will occur opposite a clean, salt water saturated sand. Shale or clay in sand depresses the self-potential and oil in sand may cause a jagged self-potential curve so that a reliable maximum cannot be determined. (2) Measure sp_f in a laboratory filtration cell. (3) Calculate SP_f for the filtration pressure difference in the well. (4) Determine the electrochemical self-potential by the equation, $SP_e = SP_{total} - SP_f$. (5) Measure the resistivity of the drilling mud and calculate (R_{mud}/R_{wtr}) from the equation,

$$\frac{R_{mud}}{R_{wtr}} = e^{\frac{SP_e}{K}}$$

Determine formation water salinity from Wylie's chart of resistivity as a function of salinity.[1]

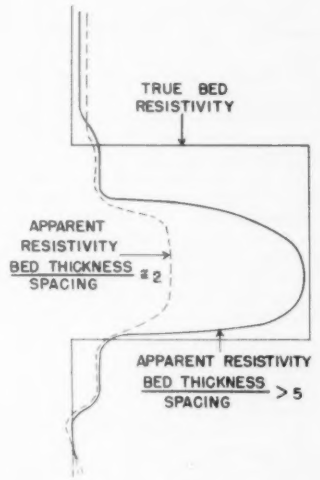

FIG. 1

Resistivity Log

The resistivity log measures the apparent resistivity of formations opposite the logging instrument. If these formations were homogeneous, vertically and horizontally, and if the resistance of well bore fluids was the same as the formation resistivity, the electric log would measure a true resistivity. Fig. 1 shows the deviation due to vertical discontinuity of the short normal resistivity curve from true resistivity. If the thickness of a high resistivity bed is more than about five times the spacing between the electrodes, measured resistivity reaches a maximum approximately equal to the true resistivity of the formation. If the bed is thinner, however, the normal curve will fall short of the true high resistivity of the formation. Lateral resistivity logs are also altered by changes in bed thickness. Fig. 2 shows the deviation of the lateral curve from true resistivity. If the bed thickness is twice the spacing between electrodes, the solid curve of Fig. 2, the measured resistivity, will rise to the true maximum after the instrument has passed about half way through the bed. But if the high resistivity bed is thinner than the electrode spacing, measured resistivity will be less than the maximum true resistivity, the dotted curve Fig. 2.

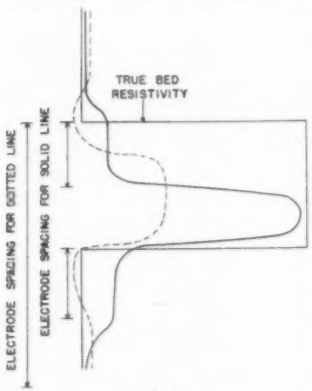

FIG. 2

Guyod[2] has calculated and plotted the relationship between measured apparent resistivity and true bed resistivity for different bed thicknesses. These correction data are, however, only approximate because of bore hole and invasion effects; and if a resistivity measurement can be obtained from a thick bed, this measurement should be used so that such corrections can be avoided.

The well bore, filled with drilling mud, and the invasion zone, filled with mud filtrate, are other inhomogeneities that change the electric log resistivity curve. If the distance between electrodes is many times greater than the well bore and invasion diameter, the bore hole and invasion effect is small, but large electrode spacing creates large bed thickness errors. The spacings that are used on logging instruments, therefore, represent a compromise between large spacing and small bore hole and invasion error, and short spacing and small bed thickness error. The electric log resistivity curve can be corrected for either bore hole effects alone, or for bore hole and invasion effects combined with the aid of "departure curves" that have been published by Schlumberger Well Surveying Corp.

Formation Factor

The water saturation of subsurface rocks can be estimated from the resistivity log with the aid of the "formation factor." Formation factor, a rock property, is the ratio of the resistivity of a formation saturated with brine to the resistivity of the saturating brine; it is related to both porosity and permeability. Highly permeable and highly porous rocks have low formation factors. Highly porous, but impermeable rocks, such as shales, usually have low formation factors. Good correlations can be obtained between porosity and formation factor and reliable formation factors can be estimated from porosity after these correlations have been established, but because correlation of formation factor with permeability is poor, formation factor cannot be estimated from permeability measurements.

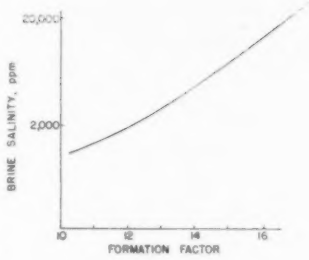

FIG. 3

If a sand contains clay, the formation factor is not a single valued property of the sand; the factor depends on the salinity of brines that saturate the sand. The conductivity of clay surfaces is independent of the salinity of the brine. If the formation water salinity is high, the contribution of clay surface conductivity to the total conductivity of the rock is small, but if the salinity is low, clay surface conductivity is a relatively large fraction of a total conductivity. As a result, formation factor decreases with decreasing water salinity. Fig. 3 shows the relationship between water salinity and measured formation factor for a sand in the San Joaquin Valley. Uncertainty about the change in formation factor caused by changes in salinity normally is more serious than uncertainty caused by other approximations that are necessary to measure formation factor and calculate water saturation.

Water Saturation

The water saturation of rock may be expressed as a function of R, the resistivity of the rock at water saturation of S_w; F, the formation factor; and R_w, the resistivity of the formation brine. R_w can be determined from the self-potential log, and R from the resistivity log as corrected with the aid of the Schlumberger departure curves. Then S_w is given by

$$S_w = (R/F \cdot R_w)^{1/n}$$

The approximation, given by Archie[3], that $n = 2$ is good for clean sandstones saturated with highly saline water, over 10,000 ppm. If the formation factor is known, this equation may be used to calculated water saturation.

Charter concluded his talk with an example analysis of an electric log from a California well. He illustrated the measurement and calculation of the filtration self-potential and of the electrochemical self-potential. He showed estimation of formation water resistivity from self-potential and illustrated methods of estimating formation factor and filtrate invasion depth by matching lateral resistivity curves from the electric log with Schlumberger resistivity departure curves.

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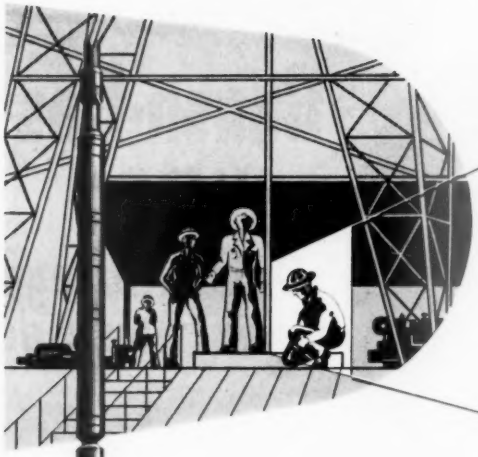

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Reservoir Fluid Properties

Reported by J. A. Klotz
Pacific Technology Forum

Marshall B. Standing, supervisor of drilling and production research for the California Research Corp., presented the fifth talk of the series that is being sponsored by the Pacific Technology Forum. Standing centered his talk on several of the reservoir fluid properties and methods for determining reservoir fluid properties that are not as well understood as they might be by most operating engineers. In particular, Standing discussed methods and apparatus used for collecting fluid samples and properties of gas condensate and dissolved gas systems.

In all analysis work, the results are useful only if the samples analyzed are representative of the large bulk of material whose processing is to be guided by the analysis. Petroleum reservoir fluid analyses are not different from other analyses: if fluid samples are not representative of the fluid that is flowing in the reservoir rock, the results can be used only after they have been altered to minimize sampling error. Unfortunately, fluid samples that are truly representative of reservoir fluids are almost impossible to obtain. Standing described three sampling methods, bottom hole sampling, recombined surface sampling, and flow line sampling; he discussed advantages and disadvantages of each of these methods, explained how sampling errors inherent in each method may be minimized, and explained the most advantageous use of each method.

Bottom Hole Samples

Bottom hole samples are obtained by running a sampling bomb down well tubing on the end of a wire line. When the bomb reaches the point in the tubing from which a sample is to be taken, valves on the sampler are activated to admit and then to trap within the bomb a sample of the fluid that happens to be within the tubing at that level. After the sampler valves are closed, the instrument is drawn to the surface. This type of sampling obtains a precise sample of the fluid that is in the tubing when the sampler was closed, but this sample is not necessarily representaive of the reservoir fluid. If the well is heading, the sampler may contain all gas or all liquid when it is closed, and even when the well is not heading, the sampler will almost certainly not collect gas and liquid in the same volumetric proportion that they exist in the reservoir rock.

To assure that a reproducible liquid sample is obtained, the well is shut in long enough to allow complete static separation of liquid and gas phases within the well bore. Two or three samples are then taken from below the liquid surface and bubble points of these samples are measured. If these bubble points agree within one or two per cent, the samples are probably representative of the reservoir liquid. Unless the reservoir contains undersaturated oil, the bubble points, when extrapolated to bottom-hole temperature, should equal bottom-hole pressure, as well as agreeing within themselves. Standing suggested that simple tests such as compressibility measurement and bubble point measurement, should be made in the field. The sampling engineer can be certain that no damage has occurred to his samples during shipping only when well head measurements, made with simple portable PVT apparatus, can be compared to laboratory measurements.

An experimental obstacle lies in determination of the temperature of the fluid sample at the time well head measurements are made. Bottom hole samples usually reach the portable PVT apparatus at a temperature that is 20 or 30°F above ambient temperature. While the bubble point pressure is being measured, the sample cools rapidly enough to make temperature measurement difficult, but too slowly to enable the operator to wait until the sample reaches ambient temperature. For most well fluids, bubble point pressure changes about five psi for 1°F temperature change.

Recombined Surface Samples

Recombined samples are taken by collecting samples of the liquid and of the gas that is produced by the well and by reblending this liquid and gas in proportions that are equal to the gas and oil production rates. If these production rates are not known accurately, the sample cannot be combined properly, and will not represent the fluid flowing in the reservoir.

Liquid production rates usually can be estimated accurately by plotting cumulative oil production as a function of time and by measuring the slope of this curve at the time the sample was taken. Samples for PVT analysis are usually taken from the discharge lines of primary traps. If the trap installation contains several stages, oil production rates measured at the last stage must be corrected for oil shrinkage to determine the production rate at the sampling point.

Gas production from each trap is usually measured by means of an orifice meter: production rates from these meters are usually accurate enough to permit good recombined samples to be made. Well production should be adjusted, however, so that gas flow through the meter is uniform; gas production from a well that is heading cannot be measured accurately.

The recombined sample method is cheaper and more convenient than the bottom hole sample, but dependence of the recombined sample on accurate gauging is a decided disadvantage. For most well fluids, the measured bubble point pressure for the recombined sample is proportional to the 0.8 power of the gas/oil ratio. Thus, if the gas/oil ratio is 15 per cent in error, the bubble point pressure measured for a recombined sample will deviate from the bubble point pressure of reservoir fluid by 12 per cent.

One of the chief uses of recombined sampling has been in the development of generalized relationships between properties of petroleum fluids. For this work, gas and oil fractions of the sample need not be recombined so that the sample represents the fluid in any particular reservoir. In fact, measurements are made on several different combinations of the same gas and liquid samples to determine such general relationships as the 0.8 power dependence of bubble point pressure on gas/oil ratio that was stated in the preceding paragraph.

Flow Line Samples

If field tank and trap systems are arranged so that several wells feed into a single trap, flow line sampling is usually the most convenient method of obtaining samples from individual wells. In the usual flow line sampling assembly, a

sampling tube extends into the flow line through a tee. The samples obtained by this method depend on the homogeneity of the fluid that is flowing in the flow lines. For example, most of the liquid from condensate wells travels through flow lines as a thin layer on the walls of the pipe, the remainder is carried as entrained droplets in the gas stream. Relative proportions of gas and liquid that enter the sampling tube depend on the relative fluid velocities in the flow line and the sampling tube. If these velocities are the same, the fluid in the sampling tube will have the same composition as the fluid in the center of the flow line. A larger proportion of liquid may be drawn into the sampling tube, however, by withdrawing the sample at a velocity lower than that of the flow line fluid. Thus flow line sampling can be used to produce accurate samples only if the proper sampling rate is determined.

Usually, however, the "correct" sampling rate is not determined; all samples are withdrawn at the same rate. Flow line sampling is used to produce samples which, even though they are not truly representative of the reservoir fluid, can be used to detect changes of the reservoir fluid with time.

Gas Condensate Systems

Most gas condensate wells are not easily distinguished from dry gas wells by observing their production behavior alone. The only reliable method of differentiating between these two types of gas wells is to run complete PVT analyses. If the critical temperature of the reservoir fluid system *is* above reservoir temperature, the reservoir is a dissolved gas system. On the other hand, a critical temperature that is below reservoir temperatures indicates that the reservoir is a gas condensate system.

These systems are characterized by the behavior known as retrograde condensation. That is, as pressure on the fluid decreases, at constant reservoir temperature, a liquid phase condenses and the portion of liquid in the reservoir increases as pressure is decreased. In a typical gas condensate system the fraction of liquid may increase from no liquid at original reservoir pressure to near five per cent liquid at a pressure that is 1,000 psi lower. If a gas condensate reservoir is produced by pressure depletion as a dissolved gas reservoir would be produced, a large portion of the heavier hydrocarbons (originally in the gas phase in the reservoir) will condense. This liquid phase cannot be produced until it revaporizes when reservoir pressure declines to about 1,000 psi. The quantity of liquid that condenses and re-evaporates as the pressure declines depends on the composition of the system and on the relationship of original reservoir pressure and temperature to critical pressure and temperature of the reservoir fluid. For some gas condensate systems, much liquid condenses with a small drop in pressure. This liquid then revaporizes slowly as the pressure declines; vaporization may not be complete until the pressure is very low. For other gas condensate systems, liquid condenses slowly as the pressure declines and then evaporates rapidly.

The first liquid that condenses as pressure is reduced in a gas condensate system is strange to our usual conception of oil. The liquids are light, about 20 or 30 pcf. They contain a large proportion of liquid methane, between 50 and 60 mol per cent. As the pressure of the system decreases, the fraction of liquid methane decreases to zero at low pressures, and the liquid density increases as methane vaporizes and heptanes and heavier hydrocarbons condense. The gas in equilibrium with this liquid has more normal properties: usually a high proportion (about 80 mol per cent) of methane. The concentration of heptanes and heavier in the gas at pressures just below the retrograde dewpoint is, however, larger than normal. This concentration decreases sharply as pressure declines and heptanes and heavier condense.

Dissolved Gas Systems

These reservoir fluid systems are differentiated from gas condensate systems by the fact that the critical temperature of a dissolved gas system is above the reservoir temperature. These systems do not exhibit retrograde condensation; they behave like normal fluids — as the pressure drops, the proportion of gas increases continuously. Because dissolved gas systems are more common than gas condensate systems, most engineers are familiar with the behavior of dissolved gas systems. Standing did not, therefore, discuss these systems as thoroughly as the gas condensate systems. Instead, he limited his discussion to an attempt to dissipate confusion that arises because vaporization process that occurs in traps is a flash vaporization, whereas vaporization process that occurs within the reservoir as the pressure is slowly reduced is a differential process.

In the process (known as flash or equilibrium vaporization) that occurs in traps, all of the gas that is vaporized remains in contact with all of the liquid so that the two are very nearly in equilibrium with each other throughout the vaporization process. Within the reservoir, however, liquid and gas are both withdrawn bit by bit; fluid remaining within the reservoir vaporizes slowly as the pressure declines. As gas is evolved from the remaining liquid, properties of this liquid change and the gas that first comes out of solution will not be the same as the gas that comes out of solution later in the life of the reservoir. Also, the first gas will not be in equilibrium with the liquid that remains in the reservoir at the lower pressure. The quantity of gas that vaporizes from a liquid sample as the pressure is dropped, for example from 1,000 psi to 100 psi, will depend on the path of the vaporization process. The volume of solution gas and the liquid shrinkage will be different if the process is a single stage flash vaporization than if the process is a two- or three-stage flash vaporization, or a differential vaporization. In the field, gas/oil ratios are usually reported as cubic feet of gas per barrel of tank oil. Both gas volume and oil volume are measured for fluids that leave the last stage of the trap setting. Engineers do not always remember, however, that these gas/oil ratios depend on the history of the oil and gas as they flow from the reservoir to the production lines.

In order to clarify these two types of vaporization, Standing defined the following terms: (1) Formation volume factor, the volume of a quantity of reservoir oil divided by the volume to which this quantity of oil has shrunk by the time it reaches the field stock tanks. This shrinkage is primarily caused by flash vaporization of gas within the trap. (2) Relative oil volume, the ratio of the residual volume of oil to its original volume. (3) Residual volume, the oil volume remaining after gas has been evolved by a differential vaporization process. The path of oil from the reservoir to the stock tank involves both of these processes: differential vaporization, as the oil evolves gas while it remains within the reservoir; flash vaporization, as it travels up the tubing and into the production trap. Both the formation volume factor and the relative oil volume must be considered before an accurate estimate of original oil volume can be made.

Because oil shrinkage within the trap depends on the pressure at which the trap is operated, the volume of tank oil that is produced for each volume of reservoir oil flowing can be changed by changing trap pressures or by changing the number of trap stages. A 15-20 per cent increase in tank oil production may often be obtained by adding a second stage to the trap setting.

Standing closed his talk by presenting a glossary relating to hydrocarbon behavior. This glossary contained short, clear, definitions of about 90 terms that are used to discuss the behavior and properties of petroleum reservoir fluids. ★ ★ ★

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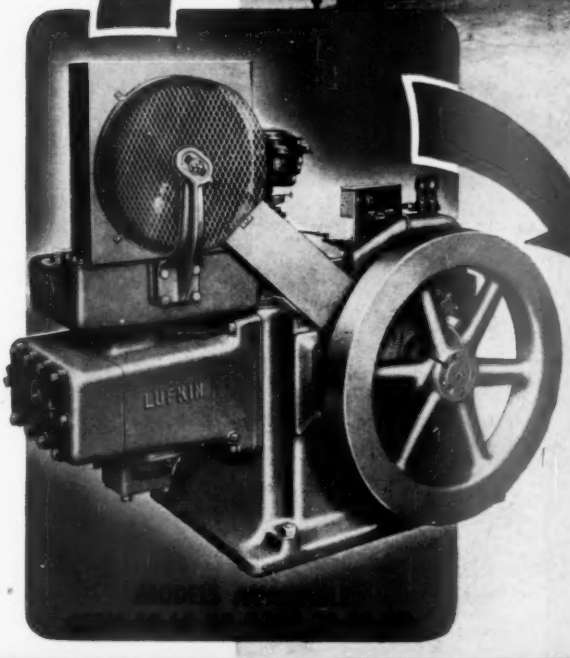

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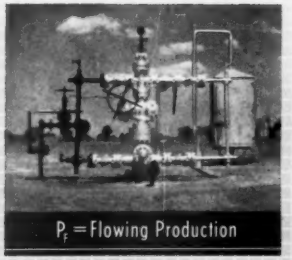
Where;

R=Research

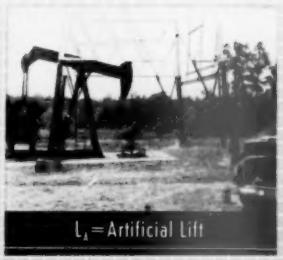
E_x=Exploration

D_R=Drilling

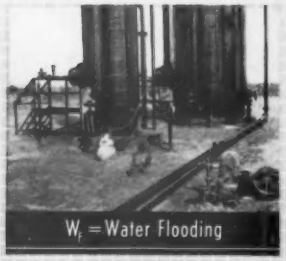
W_c=Well Completion



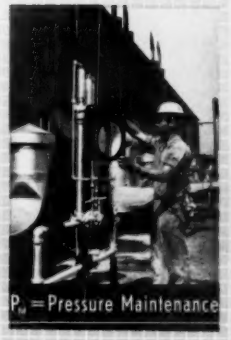
P_F=Flowing Production



L_A=Artificial Lift



W_F=Water Flooding



P_M=Pressure Maintenance

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Drilling, Gas, Production Technology To Highlight AIME Petroleum Branch Fall Meeting

FORTY-TWO PAPERS AUTHORED BY NATION'S TOP ENGINEERS TO BE PRESENTED OCT. 1-3

HOUSTON — one of the world's chief oil centers, the nation's No. 2 port and the South's largest metropolis — is the target of hundreds of this country's leading petroleum engineers who will converge there Oct. 1 for the three-day Annual Mid-Continent Fall Meeting of the Petroleum Branch, AIME.

Upwards of 1,200 engineers and their wives are expected to check in at the South Texas city's top hotels for three days of technical and business meetings, social functions and informal tours of the area's equipment manufacturing and service company facilities. A program of 42 technical, economic and business papers have been written and will be presented by some of the industry's most outstanding scientists, engineers and company executives. A complete program of events may be found on Page 35, Sec. 1.

Registration will begin at 5 p.m. Tuesday, Sept. 30, the registration desk remaining open until 9 p.m. on the mezzanine floor of the Rice Hotel in the heart of downtown Houston. All technical sessions will be held in the Rice Hotel's several meeting rooms. The first formal session, on production equipment, will get underway at 9 a.m., Oct. 1, in the Ballroom of the Rice. A concurrent session on well completion practices will begin at the same time in the South American Room. Both sessions will end at 11:15 a.m. Each offers three outstanding papers on subjects within its own field.

Welcoming Luncheon

The annual Welcoming Luncheon will be held in the Ballroom of the Rice at 12 noon Wednesday. The keynote speaker for the luncheon will be William K. Whiteford, executive vice-president of the Gulf Oil Corp. This function is expected to attract some 750 members and guests, having proven to be in the past one of the major social events of the meetings.

The Wednesday afternoon technical session will get underway at 2:30 p.m. in the Ballroom. A general interest session, it will be comprised of three papers. A highlight of the session will be a talk by M. L. Haider, president of the AIME and vice-president of Standard Oil Co. (N.J.). President Haider's talk will be "The Professional Status of the Petroleum Engineer."

Wednesday evening will be highlighted by a reception and buffet around the swimming pool of the Shamrock Hotel. This

function is open for all members and their wives or guests. The natural setting of the Shamrock pool promises a pleasant social period and will enable those attending to strike up new acquaintances and renew old ones. The evening will begin with cocktails followed by the buffet. All will be capped by an aquacade and water show in the pool.

The drilling technology session will begin at 8:30 a.m. Thursday, Oct. 2, in the South American Room of the Rice with four papers scheduled. Another morning session, on production operations and water flooding, will be conducted in the Ballroom of the Rice. Here again, four papers will be given. All papers will be presented within a predetermined time limit but discussion of each paper, open to anyone wishing to offer comment, will not be limited as to time. This system of procedure was first instigated at the Mid-Continent Fall Meeting of the Petroleum Branch, AIME, held in New Orleans in 1950. It proved to be so popular that it was repeated in Oklahoma City in 1951 and will again be used this year in Houston.

Open Meeting of Executive Committee

The open meeting of the Petroleum Branch Executive Committee will be held from 1:30 p.m. to 5 p.m. Thursday, Oct. 2, in the Jade Room of the Rice Hotel. This meeting, one of the most important executive meetings of the Branch, is open to all members who care to attend. Comments are often invited from the floor. The meeting will be presided over by Paul Turnbull of the La Gloria Corp., chairman of the Petroleum Branch for 1952.

A technical session on well completion and logging will be held in the Ballroom from 2:00 p.m. to 5:00 p.m. Thursday with four papers being given by outstanding authors in their fields. Also Thursday afternoon from 1:30 p.m. to 5:00 p.m. a gas technology session will be held in the South American Room where five papers on this subject will be presented.

Thursday evening, the Annual Petroleum Branch Dinner and Dance will be held in the Rice Ballroom from 8:00 p.m. to 1 a.m. No formal program will be offered.

An economics and management session will be held in the South American Room of the Rice Friday morning from 9:00 a.m. to 12 m. One of the highlights of this session will be a paper on the impact of the Williston Basin on the supply and demand relationship throughout the Rocky Mountain and Alberta crude producing areas, by John Winger of the Chase National Bank.

Concurrently, from 8:30 a.m. to 12 m. a production research session will be held in the Ballroom of the Rice with five papers being given. This session will be continued from 1:30 p.m. to 5:00 p.m. at the same location with an additional four papers to be presented. Also from 1:30 p.m. to 4:00 p.m., a session on production operations will be held in the South American Room. Here again four papers will be given by outstanding authors.

One of the highlights of the entire meeting will be a field trip, open to all members attending, to the facilities of the Texas Gulf Sulphur Co. headquarters at Newgulf, some 50 miles southwest of Houston. Located there is one of the largest sulphur mining operations in the world. The tour is open also to wives of members. The trip to Newgulf will be made in chartered busses which will leave the Rice Hotel at 1:00 p.m. and will return about 6:30 p.m. The mining of sulphur and the processes used in its storage are as fascinating to witness as comparable petroleum industry operations. Here is offered a rare opportunity for camera enthusiasts to catch the absolute contrasts of blazing yellow sulphur and deep blue skys on color film.

In addition to the program of papers, a number of business meetings will be held by various committees of the Petroleum Branch. The Petroleum Section Conference, just formed this year, will be held at 2:30 p.m. Wednesday, Oct. 1. This Conference is made up of chairmen and a delegate of each of the various Petroleum Local Sections and Chapters of the AIME. The Conference will discuss problems relating to Petroleum Branch members and offer suggestions to the Executive Committee as to how such problems should be met and resolved. There will also be meetings of the Membership Committee, the Advertising Committee and possibly the Publications Committee.

The Gulf Coast Section, under the chairmanship of George R. Gray, will act as hosts for the meeting. Other officers of the Section are R. C. Craze, Humble Oil and Refining Co., vice-chairman; A. B. Stevens, A&M College, vice-chairman; R. M. Rutledge, Lane-Wells Co., secretary-treasurer; A. S. Trube, Tide Water Associated Oil Co., membership; Leon Singleton, Houston Oil Field Material Co., Journal secretary, and directors R. M. Darling, Stanolind Oil and Gas Co.; H. A. Otto, Tennessee Gas Transmission Co.; A. W. Waddill, Houston Oil Field Material Co.; and J. R. Welch, Humble Oil and Refining Co. ★ ★ ★

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PROGRAM

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11:30 AM — Board bus at Texas Avenue entrance Rice Hotel.

12:00 Noon — Quick tour and buffet luncheon.

1:00 PM — Product display and rig demonstration of NEW A-1 tool.

2:30 PM — Bus back at Rice Hotel.

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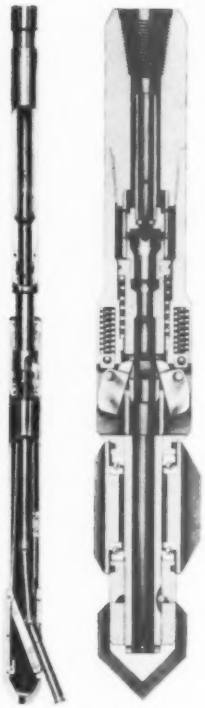

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PROGRAM

of

Papers and Activities

PETROLEUM BRANCH, AIME, FALL MEETING

Rice Hotel **Houston, Texas** **October 1, 2, 3, 1952**

(All papers shown are subject to change or withdrawal.)

Tuesday, September 30

5:00 p.m. to 9:00 p.m. — Advance Registration
Mezzanine

Wednesday, October 1

8:00 a.m. to 5:00 p.m. — Registration and Exhibits
Mezzanine

9:00 a.m. to 11:15 a.m. — Technical Session — Production Equipment — Ballroom

200-G: *Use of the Automatic 'Free Piston' in Oil Well Production Problems*, by E. D. McMURRY, Garrett Oil Tools, Inc.

231-G: *Permanent Type Well Completion*, by T. A. HUBER and G. H. TAUSCH, Humble Oil and Refining Co.

202-G: *A High Pressure Wellhead Lubricator*, by HOWARD E. McKINNEY, Shell Oil Co.

For the Ladies — Morning Sherry — Rice Hotel

9:00 a.m. to 11:15 a.m. — Technical Session — Well Completion
South American Room

203-G: *The Skin Effect and its Influence on the Productive Capacity of a Well*, by A. F. VAN EVERDINGEN, Shell Oil Co.

204-G: *Improved Techniques Developed for Acidizing Gas Producing and Injection Wells*, by W. H. JUSTICE and JENS P. NIELSEN, La Gloria Corp.

205-G: *Rock Rupture as Affected by Fluid Properties*, by P. P. SCOTT, JR., W. G. BEARDEN, and G. C. HOWARD, Stanolind Oil and Gas Co.

12:00 m. to 2:00 p.m. — Welcoming Luncheon for Ladies and Gentlemen — Ballroom. Speaker, W. K. Whiteford, Executive Vice-President, Gulf Oil Corp.

2:30 p.m. — Petroleum Section Conference — Jade Room

2:30 p.m. to 5:00 p.m. — General Interest Session
Ballroom

236-G: *Educating Laymen in Oil Production*, by JACK TARNER, Phillips Petroleum Co.

237-G: *The Professional Status of the Petroleum Engineer*, by M. L. HAIDER, Standard Oil Co. (N.J.), and President, AIME, for 1952.

238-G: *The Pressure Performance of Five Fields Completed in a Common Aquifer*, by W. D. MOORE and L. G. TRUBY, JR., Humble Oil and Refining Co.

7:00 p.m. to 10:00 p.m. — Buffet Supper for Ladies and Gentlemen — Shamrock Hotel

Thursday, October 2

For the Ladies — Tour of Houston

8:30 a.m. to 11:15 a.m.—Technical Session—Drilling Technology
South American Room

207-G: *An Inhibited Mud for Drilling Water-Sensitive Pay Zones*, by G. E. HENDRICKSON, Cities Service Oil Co.

208-G: *Fluid Mechanics of an Oil Well Drilling String*, by WILLIAM M. KOCH, Reed Roller Bit Co.

209-G: *Use of Charcoal in Cement to Combat Effects of Contamination by Drilling Muds*, by B. E. MORGAN and G. K. DUMBAULD, Humble Oil and Refining Co.

234-G: *A Method of Perforating Casing Below Tubing*, by M. P. LEBOURG and G. R. HODGSON, Schlumberger Well Surveying Corp.

9:00 a.m. to 12:00 m. — Technical Session — Production Operations - Water Flooding — Ballroom

211-G: *X-Ray Shadowgraph Studies of Areal Sweepout Efficiencies*, by R. L. SLOBOD and B. H. CAUDLE, The Atlantic Refining Co.

212-G: *Water Flooding in North Government Wells Field, Duval County, Texas*, by D. M. COLLINGWOOD and R. J. BETHANCOURT, Sun Oil Co.

213-G: *Properties of Linear Water Floods*, by L. A. RAPOPORT and W. J. LEAS, The Carter Oil Co.

235-G: *Improving Production by Chemical Treatment in Gulf Coast Area*, by BURTON AULICK, H. F. HOPKINS, FRANK SAYE and WAYNE HOWER, Halliburton Oil Well Cementing Co.

1:30 p.m. to 5:00 p.m. — Open Meeting, Branch Executive Committee — Jade Room

2:00 p.m. to 5:00 p.m. — Technical Session — Well Completion - Logging — Ballroom

215-G: *Origin of the Electric Potential Observed in Wells*, by W. M. MCCARDELL, W. O. WINSAUER and M. WILLIAMS, Humble Oil and Refining Co.

216-G: *Electrical Resistivity Measurements on Reservoir Rock Samples by the Two-Electrode and Four-Electrode Methods*, by CARL F. RUST, Magnolia Petroleum Co.

192-G: *Neutron Derived Porosity — Influence of Bore Hole Diameter*, by C. B. SCOTTY and E. F. EGAN, The Texas Co.

217-G: *The MicroLaterolog*, by H. G. DOLL, Schlumberger Well Surveying Corp.

1:30 p.m. to 5:00 p.m. — Technical Session — Gas Technology South American Room

218-G: *A Laboratory Investigation of Oil Displacement from Porous Media by a Liquefied Petroleum Gas*, by J. H. HENDERSON, Gulf Research and Development Co., N. B. GOVE, H. J. LEDBETTER and J. D. GRIFFITH, Gulf Oil Corp.

193-G: *Low Temperature Phase and Volumetric Behavior of Natural Gases*, by T. L. GORE, Standard Oil Co. (Ind.), P. C. DAVIS, Ethyl Corp., and F. KURATA, University of Kansas.

233-G: *Pressure Gradients in Natural Gas Reservoirs*, by DAVID CORNELL, University of Texas, and DONALD L. KATZ, University of Michigan.

190-G: *Desorption of Hydrocarbons from an Unconsolidated Sand*, by CHARLES W. OXFORD, University of Arkansas, and R. L. HUNTINGTON, University of Oklahoma.

Paper for Discussion Only

219-G: *Equilibrium Constants for a Gas-Condensate System*, by A. E. HOFFMAN, J. S. CRUMP and C. R. HOCOTT, Humble Oil and Refining Co.

For the Ladies — Style Show Tea at Sakowitz Sky Terrace

8:00 p.m. to 1:00 a.m. — Petroleum Branch Banquet and Dance Ballroom

Friday, October 3

9:00 a.m. to 12:00 m. — Economics and Management Session South American Room

A paper on the impact of the Williston Basin on the supply and demand relationship throughout the Rocky Mountain and Alberta crude producing areas, by JOHN WINGER, Chase National Bank.

A paper on the Middle East situation, by WALTER LEVY, Petroleum Consultant.

Two other papers on economics and management.

8:30 a.m. to 12:00 m. — Technical Session—Production Research Ballroom

194-G: *Variables Affecting Restored-State Determination of In-Place Oil*, by HENRY LEWELLING and W. E. GRUBB, The Atlantic Refining Co.

220-G: *Determination of Limestone Performance Characteristics by Model Flow Tests*, by C. R. STEWART, F. F. CRAIG, JR., and R. A. MORSE, Stanolind Oil and Gas Co.

221-G: *Calculation of Unsteady-State Gas Flow Through Porous Media*, by G. H. BRUCE, D. W. PEACEMAN, H. H. RACHFORD, JR., Humble Oil and Refining Co., and J. D. RICE, Rice Institute.

222-G: *Surface Area Measurements on Sedimentary Rocks*, by C. S. BROOKS and W. R. PURCELL, Shell Oil Co.

223-G: *Formation Factors of Unconsolidated Porous Media: Influence of Particle Shape and Effect of Cementation*, by M. R. J. WYLLIE and A. R. GREGORY, Gulf Research and Development Co.

1:00 p.m. — Field Trip to Texas Gulf Sulphur Co., Newgulf, Texas For Ladies and Gentlemen

1:30 p.m. to 5:00 p.m. — Technical Session—Production Research Ballroom

206-G: *Flow into Oil Wells Through Perforations*, by H. I. MEYER, United Gas Corp.

225-G: *Relative Permeability Calculation from Pore Size Distribution Data*, by N. T. BURDINE, Magnolia Petroleum Co.

227-G: *Theoretically Indicated Methods of Wetting Liquid Relative Permeability Measurement*, by WILLIAM H. HARTWIG, University of Texas.

232-G: *Bubble Formation in Supersaturated Hydrocarbon Mixtures*, by HARVEY T. KENNEDY, Texas A&M College, and CHARLES R. OLSON, Ohio Oil Co.

1:30 p.m. to 4:00 p.m. — Technical Session — Production Operations — South American Room

228-G: *Spraberry Permeability from Build-Up Curve Analyses*, by A. B. DYES and O. C. JOHNSTON, The Atlantic Refining Co.

229-G: *Application of the Material Balance Equation to a Partial Water Drive Reservoir*, by A. F. VAN EVERDINGEN, E. H. TIMMERMAN and J. J. MCMAHON, Shell Oil Co.

230-G: *Water Input Profile Determinations on Injection Wells in Secondary Recovery Fields*, by BLISS ADAMSON and BOB DIGGS BROWN, Halliburton Oil Well Cementing Co.

187-G: *A Method for Predicting the Tendency of Oil Field Waters to Deposit Calcium Carbonate*, by HENRY A. STIFF and LAWRENCE E. DAVIS, The Atlantic Refining Co.

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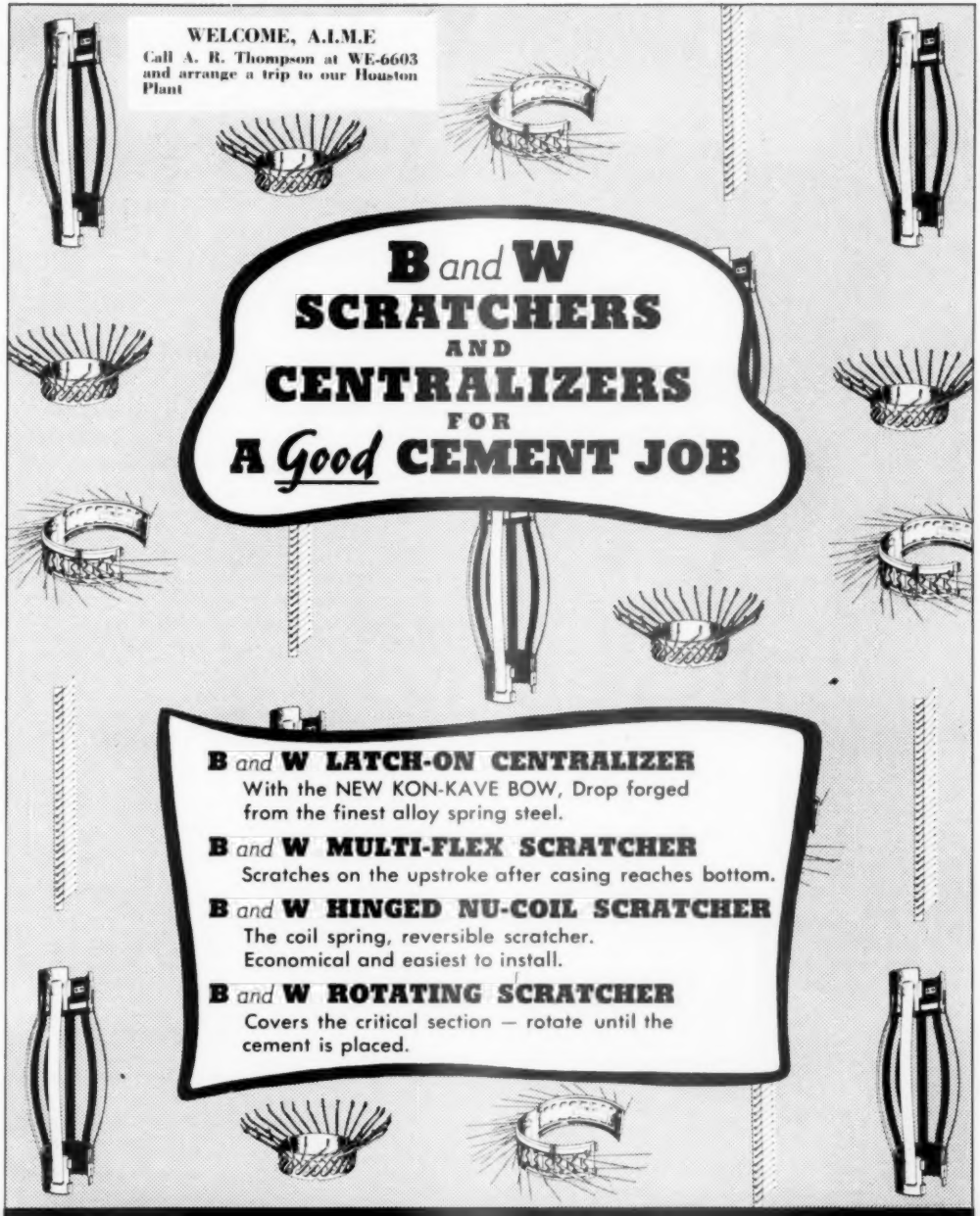

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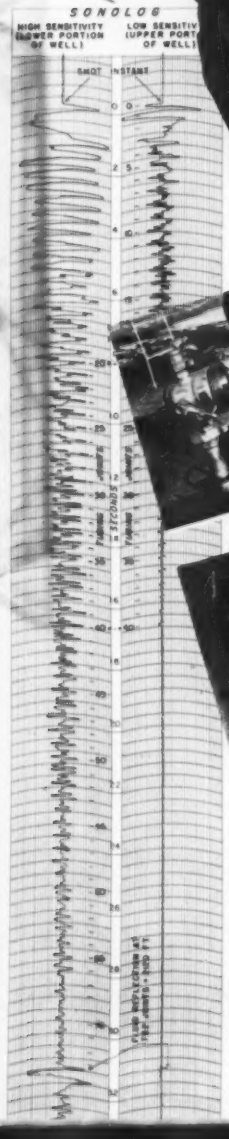

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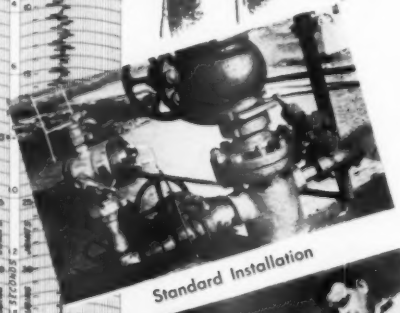

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ABSTRACTS OF PAPERS TO BE PRESENTED AT THE AIME FALL MEETING

Here Are Brief Summaries of Papers to Be Presented And a Schedule of Authors for the Houston Program

187-G

A Method for Predicting the Tendency of Oil Field Waters to Deposit Calcium Carbonate

Henry A. Stiff, Jr., and **Lawrence E. Davis,** The Atlantic Refining Co., Dallas, Tex.

The authors of this paper previously presented a method for predicting the tendency of oil field waters to deposit calcium sulfate. The present paper gives a similar method for calcium carbonate. Methods for predicting calcium carbonate scaling tendencies in fresh waters have been available for some time, but these could not be used for brines. By experimentally deriving the value of the K term in the Langelier equation, a method has been developed which applies to waters of high salt content. A statistical study is included which shows that the experimentally derived values of K are in good agreement with actual conditions. Several applications of the final equation to production practice are given.

190-G

Desorption of Hydrocarbons from an Unconsolidated Sand

Charles W. Oxford and **R. L. Huntington,** School of Chemical Engineering, University of Oklahoma, Norman, Okla.

Both pressure depletion and constant pressure flow ("sweep") methods have been studied for the recovery of some pure hydrocarbons by desorption from an unconsolidated sand. Several factors which were thought to contribute to the desorption of hydrocarbons have been treated separately. They were (a) rate of gas flow, (b) original liquid saturation, (c) reservoir temperature, and (d) presence of water and brine. The effect of pressure, size and shape of interfacial surface, presence of other components, and interfacial tension have been treated theoretically. Equations for the calculation of theoretical pressure-specific gravity curves and their limitations are presented. Pure hydrocarbons, *n*-hexane, and *n*-heptane, and a pure gas (nitrogen) were employed in most of the experiments. In addition, a run was made with a hydrocarbon condensate as the saturating liquid. Data and graphs have been presented for desorption of pure hydrocarbons at pressures ranging from 50 psia to 4,000 psia, with liquid saturation of five to 25 per cent, water content of five to 25 per cent, and withdrawal rates of 0.034 to 0.900 reservoir volumes per minute. Theoretical curves have been shown with the experimentally determined points. Data and graphs have also been presented for atmospheric sweep studies, together with curves based on equilibrium conditions. Hydrocarbon concentrations of 5.1 per cent to 34 per cent, and sweep velocities of 1.159 to 13.66 reservoir volumes per minute were employed.

192-G

Neutron Derived Porosity — Influence of Bore Hole Diameter

C. B. Scotty and **E. F. Egan,** The Texas. Co.

The neutron-gamma log has been used for stratigraphic correlation by the oil industry for a number of years. In the past few years, the quantitative application of the log to provide information with respect to porosity has received considerable attention. The basic concept of quantitative interpretation has been pointed out in the literature. This paper develops by empirical means a method whereby the relationship of porosity to neutron-gamma deflection may be predicted for various bore hole diameters. This relationship is applicable to the present commercially available neutron-gamma log run in open hole. Data available at present are insufficient to establish similar correlations for cased holes. Through the development of such a correlation, the importance of the various factors which influence the log become evident.

193-G

Low Temperature Phase and Volumetric Behavior of Natural Gases

T. L. Gore, Standard Oil Co. (Indiana), Sugar Creek, Mo.; **P. C. Davis,** Ethyl Corp., Baton Rouge, La.; and **F. Kurata,** University of Kansas, Lawrence, Kans.

An experimental method and apparatus for the study of the low-temperature phase and volumetric behavior of volatile mixtures are described. The phase diagrams, including the critical points, and the volumetric behavior of two natural gases at temperatures from –40°F to –200°F and pressures to 1,200 psi are given.

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194-G

Variables Affecting Restored-State Determination of In-Place Oil

Henry Lewelling and **W. E. Grubb, Jr.**, The Atlantic Refining Co., Dallas, Tex.

One of the important functions of the petroleum engineer is the volumetric analysis of the reservoir for an estimate of in-place oil. The reliability of the estimate is a joint function of the accuracy of basic data used and of the correctness of application. Frequently, basic data are obtained from laboratory determinations of porosity and interstitial water saturation. It follows that errors in laboratory measurement may have a serious effect on reservoir evaluation. A better understanding of the method used, of the variables that effect it, and of consistent variations that tend to yield high or low results will allow the laboratory worker to produce more accurate values. Similarly, a better understanding on the part of the engineer will permit him to use the data more intelligently so that unavoidable errors may be corrected rather than compounded, and so that an increased reliability of reservoir evaluation may result. This paper presents the results of investigations of variables which may lead to errors in some standard porosity methods, and in the restored-state (disc) determination of interstitial water. Variables of preferential wettability, clay hydration and gas absorption are shown to be interrelated in their effects. Additional variables related to equipment, technique, capillary pressures, fluid phases and calculation procedures are considered. It is shown that a report would more properly present porosity available for hydrocarbon storage than simply porosity and interstitial water content. Data obtained statistically from a quantity of restored-state and routine core analysis work are offered as supporting evidence. The variables are each treated individually, so that each may be understood separately, as well as in its interrelationship with others.

200-G

Use of the Automatic "Free Piston" in Oil Well Production Problems

E. D. McMurray, Garrett Oil Tools, Houston, Tex.

An abstract of this paper was unavailable at the time this issue went to press. An abstract will appear in the formal program of events which will be distributed at the meeting.

202-G

A High-Pressure Wellhead Lubricator

Howard E. McKinney, Shell Oil Co., Houston, Tex.

A high-pressure wellhead lubricator has been developed to facilitate telemetering electrical measurements from subsurface reservoirs to the surface with the well under normal flowing conditions. The field unit in use at the present time employs a 5/16-in. diameter, single-conductor armored cable and is to be used in wells with surface pressures up to 5,000 psi. It has a pressure sealing element that maintains a continuous and absolute seal around the cable as it enters or leaves the tubing at speeds up to 175 ft per minute. A cable injecting device is used which obviates sinker bars or weight sections on the instrument.

203-G

The Skin Effect and Its Influence on the Productive Capacity of a Well

A. F. van Everdingen, Shell Oil Co., Houston, Tex.

The pressure drop in a well per unit rate of flow is controlled by the resistance of the formation, the viscosity of the fluid, and the additional resistance concentrated around the well bore resulting from the drilling and completion technique employed and, perhaps, from the production practices used. The pressure drop cause by this additional resistance is defined in this paper as the skin effect, denoted by the symbol S. This skin effect considerably detracts from a well's capacity to produce. Methods are given to determine quantitatively (a) the value of S, (b) the final build-up pressure, and (c) the product of average permeability times the thickness of the producing formation.

204-G

Improved Techniques Developed for Acidizing Gas Producing and Injection Wells

W. H. Justice and **Jens P. Nielsen**, La Gloria Corp., Corpus Christi, Tex.

This paper describes an improved acidizing technique which has been applied in acidizing gas wells in the La Gloria Field. Wells acidized in this manner exhibited a much greater increase in deliverability than wells acidized in the conventional manner. The acid is injected into the well in small slugs separated by a small volume of high pressure gas. The acid and gas are displaced from the tubing by high pressure gas to reduce the hydrostatic head on the well when the acid is recovered from the well. The well is opened for production as soon as the acid and gas are displaced. This procedure permits a very rapid recovery of the acid which results in large increases in the deliverability of the gas wells. It has been found advantageous in the acidization of gas injection wells to inject the high pressure gas directly after the acid without backflowing the acid out of the well. This practice has made it possible to inject the gas in the injection wells of this field with a much lower pressure differential. This reduces the horsepower required to inject the gas and also decreases the number of injection wells required per reservoir.

205-G

Rock Rupture as Affected by Fluid Properties

P. P. Scott, Jr., **W. G. Bearden** and **G. C. Howard**, Stanolind Oil and Gas Co., Tulsa, Okla.

This report concerns the rupture or breakdown of rock formations as related to drilling, completing, and stimulating production of wells and comprises data compiled from literature study, from tests conducted in bores drilled into surface outcrops of rock and into cores obtained from wells in various fields, and from records of treatments of oil and gas wells. The effects of variables, such as rate of pressure application, magnitude of confining pressure around bores, viscosity of drilling or treating fluids, mechanical tensile strength of rock, extent of fluid intrusion, presence of bedding planes, degree of saturation, and diameter of bore, were observed when cylinders of rock and wells were ruptured by internal pressure. The

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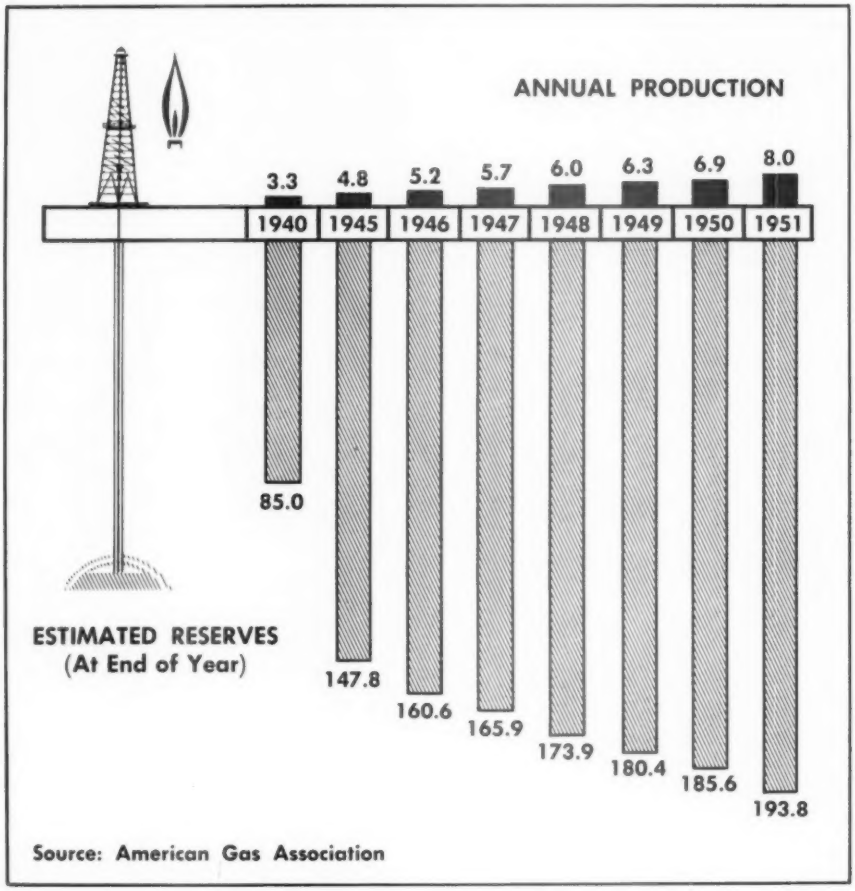

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results of tests indicate that the incidence of loss of circulation of drilling fluids is closely related to intrusion of fluids into rock, that hydraulic fracturing by intrusion of treating fluids is influenced by the viscosity and pumping rate of the drilling fluids and the anomalies of the bores, and that the theories of elastic behavior of homogeneous, impermeable, isotropic materials are not applicable to rupture of rock by internal pressure.

206-G

Flow Into Oil Wells Through Perforations

Henry Meyer, United Gas Corp.

In modern well completion, most wells are completed by perforating the casing. If this completion practice is good, the flow into the well from a given reservoir through these perforations will be essentially equal to the flow into an uncased well. In order to prescribe an efficient completion practice, it is necessary to understand the fluid mechanics of flow through these restrictions. Previous attempts at an analytic solution of the problem have involved so many simplifying assumptions that the results are quite specialized. Solutions by electrical analogy suffer from the inherent nuisance of constructing models and even more basically from the fact that the analogy between flow of an electric current through an electrolyte and fluid flow through a porous rock is not in all cases exact. This paper presents what is intended to be a more general solution of the problem of the effect of perforation on well production. It is divided into two parts. In the first part different cases are considered in which the rock is completely filled with one fluid, and for simplicity the liquid level in the well itself is taken to be above the top of the producing formation. The second part of this paper is concerned with flow of the denser fluid when the porous rock contains two immiscible fluids and there is consequently an interface between them. The body of the report is essentially a collection and explanation of mathematical solutions for special cases. The mathematical details are relegated to appendices.

207-G

An Inhibited Mud for Drilling Water-Sensitive Pay Zones

G. E. Hendrickson, Cities Service Oil Co.

Description of a water-base mud suitable for drilling, completing, or working over water-sensitive pay sands is given. This mud is inhibited by using salt, lime, and caustic soda so that its filtrate will not swell colloidal material with which it comes in contact within the pay sand. Conventional electric log can be run in this mud.

208-G

Fluid Mechanics of an Oil Well Drilling String

William M. Koch, Reed Roller Bit Co.

Although the use of the drilling fluid to control and condition the hole is well known, the advent of high jet velocities has brought purely hydraulic problems to attention. A hydraulic calculator was designed to provide quick answers to some of these problems. The surface equipment presents no new problems. However, the installation of a simple, direct reading flowmeter would have practical utility on a rig. The energy losses in the drill stem are calculated by the Hazen-Williams equation, although this assumes that the turbulent viscosity of the drilling fluid is the same as water. The tool joint constrictions were considered to be roughness and the Hazen-Williams roughness coefficient was determined from published data on drill stem pressure losses. Tests of the drill bit nozzle showed the pressure loss to vary as the 1.95 power of the flow and, inversely, as the 2.19 power of the exit area. A good production nozzle design showed an efficiency of 70 per cent. To get the full benefit of high jet velocity, the flow pattern on the bottom of the hole should not have any stagnation points. The minimum flow necessary to flush cuttings upon the return annulus determines the energy dissipated in the entire system. The pressure losses in the return annulus are difficult to determine as they vary with the plastic properties of the drilling fluid. Fortunately, these losses are a minor part of the total loss and it is possible to use a rough estimate without too much error. In view of these assumptions, the overall accuracy of the hydraulic calculator is of interest. A comparison of pressure drops calculated from field data and actual gage readings showed an average value of error of 4.6 per cent, a mean error of 0.5 per cent, and a maximum error of 15 per cent. This accuracy is sufficient to give useful answers.

209-G

Use of Charcoal in Cement to Combat Effects of Contamination by Drilling Muds

B. E. Morgan and **G. K. Dumbauld**, Humble Oil and Refining Co., Houston, Tex.

Results of laboratory investigations of the effects of drilling muds on oil well cements are presented which show that relatively large quantities of untreated muds do not seriously interfere with the setting of cement slurries, but that relatively small quantities of treated muds seriously retard the setting of cement slurries. Laboratory results also indicate that the harmful effects of contamination with treated muds can be counteracted by the addition of activated charcoal to cements. Also described is the successful use of cement containing activated charcoal for the placement of plugs in open hole after previous attempts with ordinary cement had been unsuccessful.

211-G

X-Ray Shadowgraph Studies of Areal Sweepout Efficiencies

R. L. Slobod and **B. H. Caudle**, The Atlantic Refining Co., Dallas, Tex.

In the past, the main emphasis in attacking the problem of the recovery of oil has been on the determination of fluid flow characteristics and residual oil saturation in the part of the reservoir which is contacted by a displacing phase. It is recognized that the determination of the fraction of the reservoir contacted in secondary recovery operations is also of great importance in predicting the ultimate recovery to be expected. A method is described in which radiographic techniques are used to determine these areal sweepout factors for any type of well spacing. Data showing the relationship of viscosity ratio and relative permeability to areal sweepout

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efficiency are presented for the five spot and the direct line drive well spacing patterns. Further applications of the method to studies of the displacement efficiency in the area contacted are mentioned.

212-G

Waterflooding in North Government Wells Field, Duval County, Texas

D. M. Collingwood and **R. J. Bethancourt**, Sun Oil Co., Dallas, Tex.

The use of a pilot waterflood is very desirable where all of the pertinent data necessary to initiate a full-scale waterflood is not available. This paper attempts to take a specific case and show the step by step process of starting with a pilot waterflood and progressing to a full-scale flood as results are obtained.

213-G

Properties of Linear Water Floods

L. A. Rapoport and **W. J. Leas**, The Carter Oil Co.

A detailed mathematical formulation of waterflood behavior in linear, horizontal systems is presented. Capillary pressure effects are evaluated, and differential equations accounting explicitly for these effects are derived. On the basis of the developed theory, it is recognized that the flooding behavior is dependent on the length of the flooded system. On the other hand systems of different lengths will yield the same flooding behavior when the parameters such as rate of injection, fluid viscosities, and interfacial tension are properly scaled. A series of precise flooding tests have been carried out and the pertinent features of the experimental procedure are described. The results are discussed and good agreement is found between theory and experiment. As a result of these findings a procedure is established for evaluating the behavior of field floods on the basis of tests performed with short core samples.

215-G

Origin of the Electric Potential Observed in Wells

W. M. McCardell, W. O. Winsauer and **M. Williams**, Humble Oil and Refining Co., Houston, Tex.

The mechanism by which an electrical potential difference is developed between two salt solutions separated by shale is shown to be a consequence of the electrical double layer of the shale surfaces. A mathematical derivation is presented to show the dependence of the potential on the shale characteristics and on the concentration of the salt solutions. The equations developed describe adequately the potential-concentration behavior of a long shale core. The equations also describe the variation of potential of sand-shale mixtures with variation of clay content. Ion adsorption is an important factor in the development of the surface charge on the shale, and electrical resistivity and ion transference number data are employed to estimate the increase of surface charge with concentration. Since the potential is shown to be dependent on the characteristics of the particular system, water salinities estimated from the potential log by previously proposed methods may be low in some cases.

216-G

Resistivity Measurements on Small Core Samples by the Two-Electrode and Four-Electrode Methods

Carl F. Rust, Magnolia Petroleum Co.

Experimental evidence is presented showing that reproducible formation resistivity factor measurements and resistivity index determinations on reservoir core samples may be made utilizing either the two-or four-electrode methods. Equipment is described which permits the application of either technique to the core specimen without loss of time and with a minimum amount of effort. Since electrical resistivity measurements on reservoir rocks are important not only in electric log interpretations, but also in the study of fundamental rock parameters, it was considered desirable to compare the applicability of both techniques of resistivity measurement.

217-G

The MicroLaterolog

H. G. Doll, Schlumberger Well Surveying Corp., Ridgefield, Conn.

A new electrical logging method, called MicroLaterolog, is described whereby the resistivity R_{xo} of the invaded zone close to the wall of the bore hole is measured. This method essentially comprises a system of concentric circular electrodes borne on an insulating support which is applied to the wall of the hole. A beam of current of very small diameter is focused horizontally into the formations by means of an automatic control device, and then opens widely at short distance from the wall. With this method, R_{xo} most often can be recorded directly, except when the mud cake is very thick, in which case a correction is easily provided. The basic role of factor R_{xo} in the quantitative analysis of electrical logs in terms of fluid saturation and porosity is explained. The paper is illustrated with field examples.

218-G

A Laboratory Investigation of Oil Displacement from Porous Media by a Liquefied Petroleum Gas

J. H. Henderson, Gulf Research and Development Co., Pittsburgh, Pa.; **N. B. Gove, H. J. Ledbetter** and **J. D. Griffith**, Gulf Oil Corp., Tulsa, Okla.

The results of a series of laboratory flood tests using liquid iso-butane to displace refined oils from test cores are presented and interpreted on an empirical basis. The study revealed the similarity of the miscible liquid displacement to that of the immiscible-fluid displacement mechanism. The efficiency of the iso-butane flood decreased markedly as the oil viscosity increased, but the effect of injection rate on the effectiveness of the primary production stage was negligible over the range investigated. The presence of free-gas saturation prior to iso-butane breakthrough increased the volume of iso-butane required to recover a given percentage of the oil present. Injection of liquid iso-butane prior to water flood resulted in a marked improvement in oil recovery by the water flood.

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219-G

Equilibrium Constants for a Gas-Condensate System

A. E. Hoffman, J. S. Crump and **C. R. Hocott**, Humble Oil and Refining Co., Houston, Tex.

The problem of unsteady-state gas flow through porous media leads to a second-order non-linear partial differential equation for which no analytical solution has been found. In this paper a stable numerical procedure is developed for solving the equation for production of gas at constant rate from linear and radial systems. An electronic digital computer is used to perform the numerical integration using an implicit form of an approximating difference equation. Solutions are presented in graphical form for various values of dimensionless parameters. The solutions are compared with the laboratory study of gas depletion in a linear system.

220-G

Determination of Limestone Performance Characteristics by Model Flow Tests

C. R. Stewart, F. F. Craig, Jr., and **R. A. Morse**, Stanolind Oil and Gas Co., Tulsa, Okla.

This paper presents the results of a series of model flow tests on a number of large limestone cores, having different pore configurations. For limestone cores having substantially sandstone type porosity, the production characteristics for solution and external gas drives are similar. For cores whose pore spaces were microscopically heterogeneous (*i.e.*, consisted of combinations of solution cavities, matrix, and fissures), the production characteristics for solution and external gas drives vary widely. The results of water floods, including the effect of free gas saturation and pressure differential, on each of these two general types of limestone porosity are also shown. Generalizations are made on the water flood recovery that could be expected from each of these two types of limestone porosity. The similarity between solution drive field performance and model solution drive performance on cores from the same field is shown for several cases. This indicates the feasibility of predetermining limestone field performance from such large core tests. Photomicrographs of plastic-impregnated rock thin sections of the samples tested are presented as an aid in understanding the flow test performances.

221-G

Calculation of Unsteady-State Gas Flow Through Porous Media

G. H. Bruce, D. W. Peaceman, H. H. Rachford, Jr., Humble Oil and Refining Co., Houston, Tex., and **J. D. Rice**, The Rice Institute, Houston, Tex.

Planning of the efficient operation of a gas-condensate reservoir requires a knowledge not only of the gross phase behavior of the system but also of the equilibrium distribution of the various components between the gas and condensate phases. This equilibrium distribution can be calculated with appropriate equilibrium constants. In this paper are presented equilibrium constants determined experimentally for the oil and gas phases initially present in the same reservoir and for the gas and condensate phases of the gas cap material at a series of pressures below the original reservoir pressure. Also presented is a method for the correlation of experimentally determined equilibrium constants and an example of the use of the correlation procedure in the adjustment of equilibrium constants for use on another similar gas-condensate system.

222-G

Surface Area Measurements on Sedimentary Rocks

C. S. Brooks and **W. R. Purcell**, Shell Oil Co., Houston, Tex.

The internal surfaces of rocks which are in contact with interstitial fluids are known to influence in some degree the recovery of hydrocarbons from pay zones. Despite the admitted importance of the influence of solid surfaces on hydrocarbon recovery, little information is available concerning the extent of surface of reservoir rocks. In this paper a description is given of the apparatus and procedure employed in the determination of the surface areas of sedimentary rocks, and values are reported for a variety of sandstone and limestone cores. In addition, consideration is given to the Kozeny equation, which relates surface area to porosity and permeability. A comparison is made between the surface areas as calculated from this equation and the geometrical areas of a series of packs of spherical glass beads. Also, for a group of sandstone cores, Kozeny areas are compared with surface areas as determined by the gas adsorption method employed in this investigation.

223-G

Formation Factors of Unconsolidated Porous Media: Influence of Particle Shape and Effect of Cementation

M. R. J. Wyllie and **A. R. Gregory**, Gulf Research and Development Co., Pittsburgh, Pa.

The literature reveals that scant attention has been paid to the systematic experimental determination of the formation factors of unconsolidated porous media. No experiments appear to have been made on the effect of increasing cementation on the formation factor of an initially unconsolidated porous medium. Measurements have accordingly been made of formation factor as a function of porosity for spheres in the porosity range 12-56 per cent and of cubes, cylinders, discs and triangular prisms over the porosity range 30-45 per cent. The results are examined in the light of the theoretical equations of Clerk Maxwell, Fricke and Slawinski. Packings of unconsolidated spheres and beach sands have been artificially cemented with silica and the formation factor-porosity relationships determined. A theory is outlined which seeks to explain the results obtained and which postulates that formation factor and porosity data for consolidated sandstones may be used to determine the original porosity of the unconsolidated sands from which the consolidated sandstones were derived. It follows also that for consolidated sandstones $F = C\phi^{k}$ where F is formation factor, ϕ fractional porosity and C and k are constants.

225-G

Relative Permeability Calculations from Pore Size Distribution Data

N. T. Burdine, Magnolia Petroleum Co.

Formulas for calculating relative permeability from pore size distribution data are derived from basic laws of fluid flow in porous media. The tortuosity factors that appear in the equations are described in terms of the physical properties of the medium and the saturations of the contained fluids. Procedures for calculating and methods for measuring the tortuosity factors are discussed. Values of relative permeability calculated by the formulas are compared with results obtained by experimental measurements.

227-G

Theoretically Indicated Methods of Wetting-Liquid Relative Permeability Measurement

William H. Hartwig, Assistant Professor of Electrical Engineering, The University of Texas, Austin, Tex.

Methods of measuring wetting-liquid relative permeability by the Hassler scheme are characterized by the long time required to reach equilibrium. This long time is necessary because of the exponential rise of the manometer column. Assuming the electrical analog of Hassler to be valid, it can be shown that the final value of the manometer level can be calculated. Of even more importance, however, is the presentation of a theoretical scheme for making the measurement independent of time. The proposed method, called the "Comparison" method, modifies the Hassler scheme by using two manometers instead of one. One manometer is connected as usual; the other is connected across a "standard" core sample and is in series with the first. The equations of the system show the resistance of the unknown sample and the resistance of the standard are in the same ratio as the ratio of the manometer readings at any time after the pressure is applied. The only condition to be met is that the Time-Constant of both manometers be the same. In examining the consequences of an error in this requirement, it is found that the error reduces slowly to zero as time passes and that the maximum error is equal to the error in the equality.

228-G

Spraberry Permeability from Build-up Curve Analyses

A. B. Dyes and **O. C. Johnston,** The Atlantic Refining Co., Dallas, Tex.

This paper shows the application of a method for analyzing pressure build-up curve to determine the effective permeability in the Spraberry. Sixteen Upper Spraberry wells of the Driver area are analyzed and show variations in the in-place effective permeability of 2 to 183 md. Since these values are much larger than the .5 md. or less reported for the matrix rock, a large part of the fractures noted in Spraberry cores must be considered native to the formation. The effectiveness of the well fracture treatment in connecting the well bore to the native fracture system is analyzed by comparison of the effective permeability as determined from the PI test to that obtained from a pressure build-up curve. These results show that the well fracture treatment is effective in connecting the well to the native fracture system well enough to yield a flow capacity within about ±50 per cent of that dictated by the native fracture system. About two-thirds of the wells show some degree of local blockage.

229-G

Application of the Material Balance Equation to a Partial Water Drive Reservoir

A. F. van Everdingen, E. H. Timmerman and **J. J. McMahon,** Shell Oil Co., Houston, Tex.

The paper contains a method which combines the material balance equation with the water influx equation to obtain reliable values for the active oil originally in place and a quantitative evaluation of the cumulative water influx. The method is illustrated by an application to a reservoir without original gas cap. In the absence of an original gas cap, results may be obtained using only field production and pressure data, PVT analyses, and a minimum of subsurface information.

230-G

Water Input Profile Determinations on Injection Wells in Secondary Recovery Fields

Bliss Adamson, Halliburton Oil Well Cementing Co.

The knowledge of the distribution of input water in injection wells is important to the success of water flood secondary recovery projects. The presence of thief formations, the lack of complete well history, and improper completion methods all contribute to diverting the flood water from the producing horizon. Through the use of known tools and procedures, input profiles can be obtained. The interface velocity procedure coupled with caliper and correlation logs give satisfactory input profiles. These provide the data to detect the presence of the undesirable conditions and for the method of correction. Under normal conditions the correlation between input profile data and permeability data from cores is good.

231-G

Permanent-Type Well Completion

T. A. Huber and **G. H. Tausch,** Humble Oil and Refining Co.

Very encouraging progress has been made in the development of the permanent-type well completion which decreases considerably the cost of completions and workovers and aids in the acquisition of reliable reservoir information at low cost. Completion and remedial operations are performed with tools which pass through the well tubing. Perforating and plug-back operations can be done with the tubing in place and do not require pipe-handling equipment. Because of the many advantages afforded by this method, development work is going forward in anticipation of ultimately being able to use it to perform all usual well completion and workover operations. Effort is also being directed to the development of a more permanent type of lift equipment suitable for use with the permanent-type well completion.

232-G

Bubble Formation in Supersaturated Hydrocarbon Mixtures

Harvey T. Kennedy, Texas A&M College, and **Charles R. Olson**, Ohio Oil Co., Shreveport, La.

In many investigations of the performance of petroleum reservoirs the assumption is made that the liquid, if below its bubble-point pressure, is at all times in equilibrium with gas. On the other hand, observations by numerous investigators have indicated that gas-liquid systems including hydrocarbon systems, may exhibit supersaturation to the extent of many hundred pounds per square inch in the laboratory. Up to the present, there has been no reliable data on which to judge the actual extent of supersaturation under conditions approaching those existing in petroleum reservoirs. The work reported here deals with observations and measurements on mixtures of methane and kerosene in the presence of silica and calcite crystals. Bubbles were observed to form on crystal-hydrocarbon surfaces in preference to the glass-hydrocarbon interface or to the body of the liquid. Statistically, it was found that the number of bubbles formed per second per square centimeter of crystal surface was a function of the supersaturation only, and the function was evaluated graphically. Supersaturations were observed up to 770 psi, under which condition bubbles formed quickly and with considerable violence. With decreasing degrees of supersaturation, the frequency of bubble formation became less, until at 30 psi supersaturation and lower, no bubbles were observed to form, even though the observation at 30 psi was continued for 138 hours. It was found that silica and calcite crystals had identical effects, within experimental error, in accelerating the formation of bubbles, and that small amounts of water and crude oil had no effect on the results.

233-G

Pressure Gradients in Natural Gas Reservoirs

David Cornell, University of Texas, Austin, Tex., and **Donald L. Katz**, University of Michigan, Ann Arbor, Mich.

Procedures for computing turbulent flow of gas in steady state near the well bore and a graphical method for predicting unsteady state laminar flow at distances from the well have been combined to compute pressure gradients in gas reservoirs. Methods are discussed for predicting single and multiple transients at constant flow rate in an infinite reservoir, predicting constant flow rates in a finite reservoir, reproducing and interpreting back pressure test data, and prediction of the behavior of a closed-in gas well. An example of the graphical method is given for a single transient and the results are compared to a published analytical solution. A typical calculation of the pressure gradient in a reservoir and the production of gas is made starting with data from a back pressure test.

234-G

A Method of Perforating Casing Below Tubing

M. P. Lebourg and **G. R. Hodgson**, Schlumberger Well Surveying Corp.

The introduction in the field of a new type well completion called for the setting of the tubing open-ended in the well before perforating the casing. This paper will describe a new perforating tool of the shaped charge expendable type, small enough to pass through tubing and powerful enough to perforate the casing. The perforations are produced at an angle and are large enough for optimum production. Performance of this tool in targets and under various well conditions will be described. Very often no lifting equipment will be available at the well. In some cases, pressure will exist in the well at the time of the perforating operation (workover wells or multiple trip perforation); therefore, new equipment and new technique for the perforating operation had to be devised. This paper will describe this equipment and technique, particularly casing collar recording, sheave support, and cable pull-down device, this last item being necessary for wells under pressure. Results obtained with this tool in the field will be given.

236-G

Educating Laymen in Oil Production

Jack Tarner, Phillips Petroleum Co.

The oil industry often finds itself in the position of not being able to apply improved production techniques because laymen who are not familiar with oil production operations, have appeared in opposition to legislation or regulation fostering the adoption of production methods designed to economically increase the amount of oil produced from the pool. The petroleum technologist, having developed improved production techniques, must now accept the added responsibility of bringing to the public the understanding that is necessary for general adoption of those techniques, otherwise the technological improvement will fall short of its goal. An educational program successfully presented to many groups consists of demonstrating the production of oil by use of a plastic working model of the subsurface reservoir and presenting a simple explanation of the fact that oil is found in a rock; it does not produce itself but can be produced by the action of gas or water under pressure.

237-G

The Professional Status of the Petroleum Engineer

M. L. Haider, Standard Oil Co. (N.J.)

An abstract of this paper was unavailable at the time this issue went to press. An anstract will appear in the formal program of events which will be distributed at the meeting.

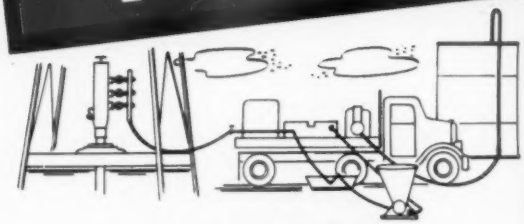
238-G

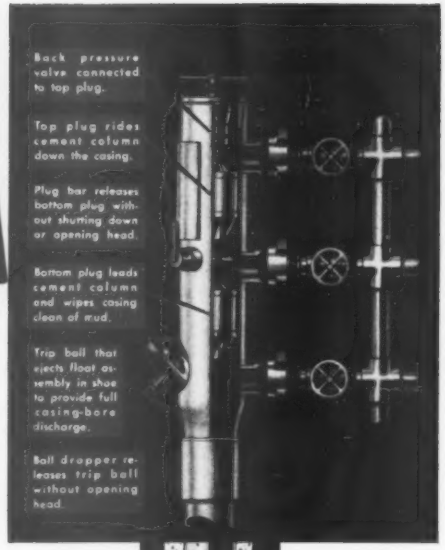
The Pressure Performance of Five Fields Completed in a Common Aquifer

W. D. Moore and **L. G. Truby, Jr.**, Humble Oil and Refining Co.

This paper presents the results obtained after calculating matches of the observed pressure performance of five fields completed in a common aquifer. A general description of the Central Basin Platform area in West Texas in which the five fields, Andector, Embar, Martin, TXL, and Wheeler, are located is contained in the paper. The method of utilizing the electric analyzer to calculate simultaneously matches of the observed pressure performance of the five fields is outlined. The determination of boundaries of pressure communication is discussed and the extent of pressure interference between fields consistent with the configuration of the area aquifer is shown graphically.

From HEAD to SHOE




Back pressure valve connected to top plug.
Top plug rides cement column down the casing.
Plug bar releases bottom plug without shutting down or opening head.
Bottom plug leads cement column and wipes casing clean of mud.
Trip ball that ejects float assembly in shoe to provide full casing-bore discharge.
Ball dropper releases trip ball without opening head.

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Hundreds of master cementing jobs by the Rector Fulbore Method prove the efficiency of its two plug method and the importance of its other exclusive features which are the basis of successful and satisfactory cementing jobs everytime. Ask your Rector Representative or authorized supply store for the complete story about better cementing with the Rector Fulbore Method.

PROTECTS AGAINST CONTAMINATION

The cement is completely and effectively segregated from well fluids by two closely fitting plugs which are positively and simply released at the proper time by mechanical means from outside the cementing head.

CLOSED CIRCUIT

Cementing head is never opened from the time cementing operations begin until they are completed. It is impossible for air pockets to form in either the mud or cement column.

FULL CASING DISCHARGE

Float assembly is pressure-ejected from the float shoe by the trip ball after casing string has been floated to position. This unrestricted opening reduces the load on the pumps . . . circulates greater volume with same pump pressure and results in higher velocity in space between casing and bottom of hole.

POSITIVE FLOW-BACK

When the back pressure valve, which has traveled down with the top plug, latches in the stall collar, it positively prevents flow-back of cement. Operator may bleed the pressure back to zero and leave the well open or close it in at final running pressure.

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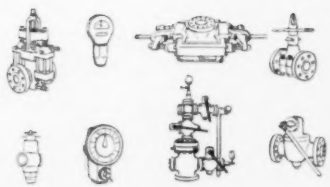
Cameron



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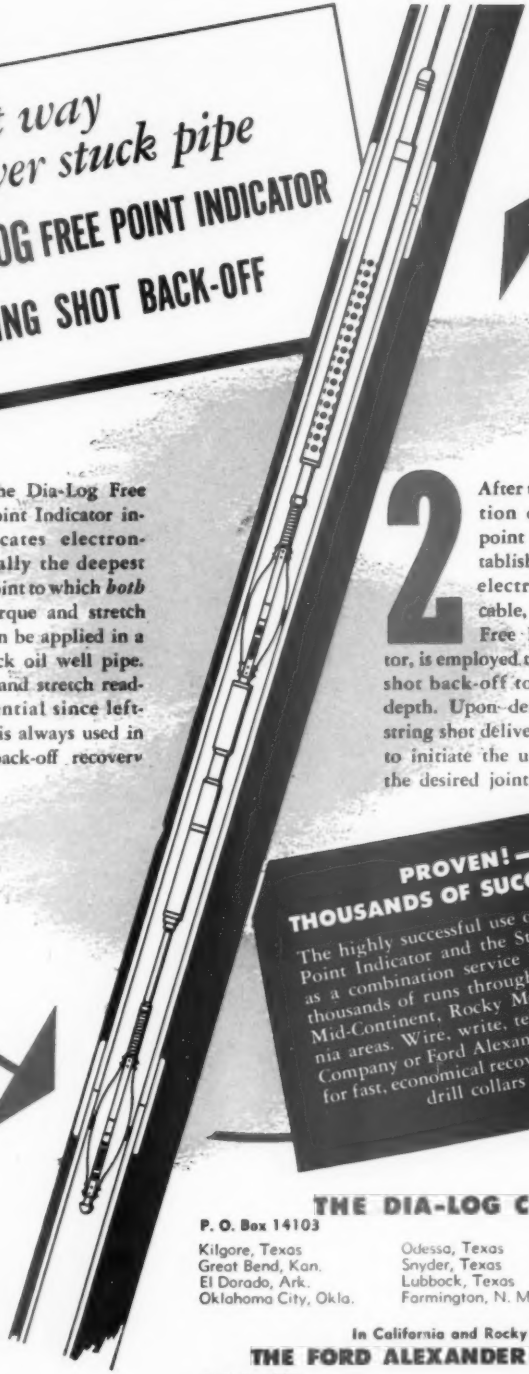
2. THE STRING SHOT BACK-OFF



1 The Dia-Log Free Point Indicator indicates electronically the deepest point to which *both* torque and stretch can be applied in a string of stuck oil well pipe. Both torque and stretch readings are essential since left-hand torque is always used in subsequent back-off recovery operations.

2 After the exact location of the stuck point has been established, the same electric conductor cable, used for the Free Point Indicator, is employed to run a string shot back-off to the desired depth. Upon detonation, the string shot delivers a sharp jar to initiate the unscrewing of the desired joint.

PROVEN! — BY THOUSANDS OF SUCCESSFUL RUNS

The highly successful use of the Dia-Log Free Point Indicator and the String Shot Back-Off as a combination service has been proved in thousands of runs throughout the Gulf Coast, Mid-Continent, Rocky Mountain and California areas. Wire, write, telephone any Dia-Log Company or Ford Alexander Corporation office for fast, economical recovery of stuck drill pipe, drill collars or tubing.

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74 sizes of X-Beans up to ½ inch

Because UNIBOLT X-Beans are drilled in increments of 5 per cent and 10 per cent of *well flow* rather than in increments of 1/64-inch in orifice size, the flow of fluid or gas from a well can now be *positively* controlled with a degree of accuracy never before attained. Say, for example, a well produces 100 bbls. through a 1/64-inch choke. To increase the choke to the next largest fractionally drilled size, 2/64-inch, would increase the production to approximately 400 bbls. On the other hand, a well that produces 100 bbls. through a size X-35 UNIBOLT X-Bean would produce only 105 bbls. through the next largest size X-Bean, X-35.5; 110 bbls. through an X-36, and so on. Here is positive protection against harmful over-producing a well in order to make its allowable, as is sometimes done through an adjustable choke.

UNIBOLT X-Beans are available in economical, renewable inserts in sizes up to X-40.5 (13/64-inch). Larger beans are standard full 6-inch length, drilled full length.

UNIBOLT Positive Choke Bodies and Cage Nipples accommodate either X-Beans or regular beans, and the Positive Choke Body may be easily converted to a Wing Valve or Adjustable Choke.

only UNIBOLT choke bodies and cage nipples accommodate X-BEANS

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Fall Meeting Officers

On this page are pictured the men heading the committees responsible for the great amount of spadework required for the successful planning and execution of a Petroleum Branch, AIME, Fall Meeting. These men of the Gulf Coast Section (exception: General Chairman W. S. Morris of the East Texas Section) deserve plaudits for their successful handling of the multiplicity of problems connected with the staging of a technical meeting . . . general meeting arrangements, registration of those attending, entertainment, hotel accommodations, publicity, ladies activities. A half year's work has been expended for this three-day meeting.

GEORGE R. GRAY
Baroid Sales Division
Chairman, Gulf Coast Section

W. S. MORRIS
East Texas Salt Water Disposal Co.
General Chairman

R. M. RUTLEDGE
Lane-Wells Co.
Sec.-Treas., Gulf Coast Section
(Picture not available)

F. S. REYNOLDS
Humble Oil & Ref. Co.
Meeting Arrangements

H. A. OTTO
Tennessee Gas Trans. Co.
Registration

J. E. KASTROP
World Oil
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K. B. FORD
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Entertainment

MRS. A. S. PARKS
Ladies Activities
Committee

R. M. DARLING
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Hotel Accommodations

R. C. CRAZE
Humble Oil & Ref. Co.
Vice-Chair., Gulf Coast Sec.

A. B. STEVENS
A&M College
Vice-Chair., Gulf Coast Sec.

J. H. ABERNATHY
Vice-Chair., Drilling

E. P. HAYES
Vice-Chair., Production

Picture Not Available

DOUGLAS RAGLAND
Chairman

W. H. JUSTICE
Vice-Chair., Gas

MILTON E. LOY
Vice-Chair., California

Branch Committees Form Up Program

Pictured above are the men responsible for the gathering of the technical papers which will be presented at the Annual Mid-Continent Fall Meeting of the Petroleum Branch, AIME, in Houston's Rice Hotel, Oct. 1-3.

These are members of the important Technology Committee. The Economics Committee, which arranged papers for the economics and management session on Friday morning, Oct. 3, is made up of Kenneth E. Hill, Chase National Bank, chairman; W. B. Barbour, Second National Bank of Houston; and L. E. Porter, Richfield Oil Corp.

The program of some 42 papers will be presented in 10 morning and afternoon sessions during the three-day meeting of the nation's leading petroleum engineers, petroleum geologists and executives. Some 1,200 members of the Petroleum Branch and their guests are expected to attend the 1952 Fall Meeting.

Beginning on page 39 are abstracts of all papers which will be given during the meeting. Included are names and company affiliations of the various authors. The "G" numbers appearing directly above each title also appear on the program on pages 35 and 36 and indicate the positions of the papers on the program and in what session they will appear. In that way, those attending the meeting may decide which papers they wish to hear presented and which sessions, where two run concurrently, they wish to attend.

The men responsible for the selection of the fine program this year are Douglas Ragland, Humble Oil and Refining Co., chairman; J. H. Abernathy, Big Chief Drilling Co., vice-chairman for drilling; E. P. Hayes, The Texas Co., vice-chairman for production; W. H. Justice, La Gloria Corp., vice-chairman for gas; and Milton E. Loy, Schlumberger Well Surveying Corp., vice-chairman for California. ★ ★ ★

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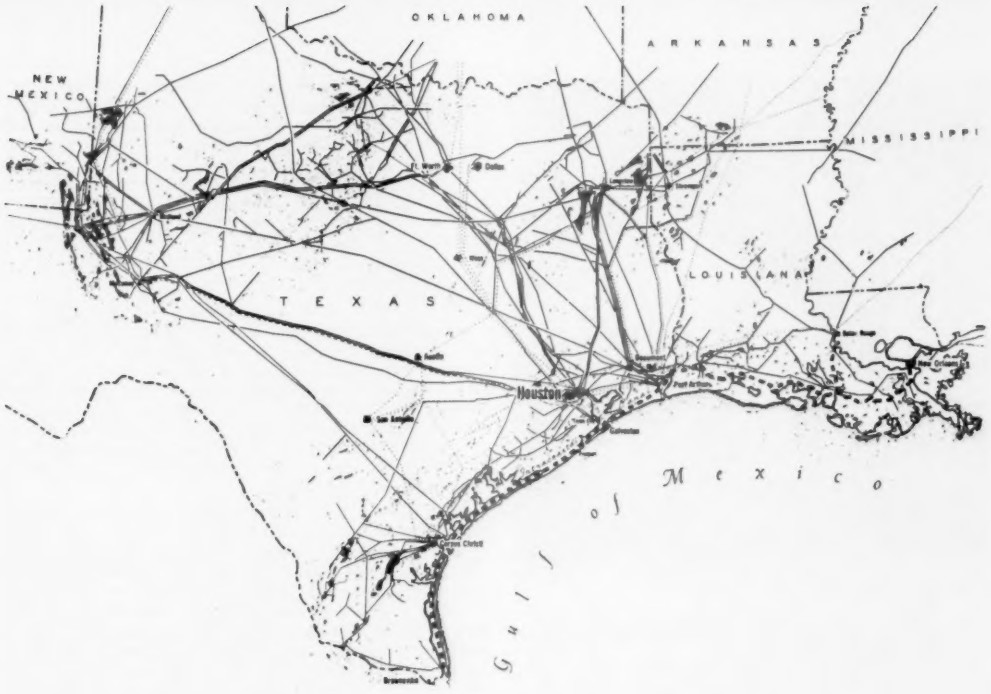


HOUSTON—Refining and Transportation Center

By T. E. Swigert
President, Shell Pipe Line Corp.

"NO great commercial production of oil will ever be secured from the State of Texas."

This conclusion, voiced just a little over 50 years ago by "experts" of the relatively young oil industry, was shattered by the roar of the Lucas gusher at Spindletop in January of 1901. Since that time, Texas has become the greatest oil producing area the world has ever known.

The state today has over 130,000 oil wells which produce about three million bbl of oil daily, a figure representing 40 per cent of total U. S. and 25 per cent of total world petroleum production.

The nerve-center of this sprawling industry is the city of Houston, a bustling metropolis of 685,000 situated 50 miles inland from the Gulf of Mexico. While the immediate Houston area has had its share of oil production — there are still producing wells within the city limits — two other phases of the industry, transportation and refining, have given the city its major claim to the title of oil capital of the state — if not of the world.

In an L-shaped area extending eastward down the Houston Ship Channel and southward to Texas City is located one of the greatest concentrations of refining facilities in the world — 11 refineries which process one-eighth of the nation's crude and turn out one-eighth of its supply of refined petroleum products. And surrounding the city like a steel cobweb is a vast network of pipe lines bringing crude into the area to be refined or transhipped and taking refined products out.

A fortunate combination of factors is responsible for Houston's becoming the petroleum refining and transportation center it is today. The most obvious is the city's close geographical relationship to the vast oil producing areas of the Southwest, which account for almost 60 per cent of the nation's crude oil supply. Lying 50 miles inland, yet a deepwater port, Houston is a logical point for the meeting of the great pipe line system with the world's ocean shipping routes and especially those to the East Coast of the United States. Also, available to Houston's plants is an abundance of cheap, efficient fuel — natural gas from the nearby Gulf Coast oil and gas fields.

Crude Supplies and Pipe Line Transportation

For a closer examination of Houston's complexed oil activities, begin at the sources of oil supply and examine the system of pipe lines which bring the crude into the Houston area from the hundreds of oil fields in the Southwest.

On a typical day a total of 900,000 bbl of crude oil arrives in this area. Roughly 30 per cent is from Gulf Coast fields and another 30 per cent originates in West Texas and New Mexico. The remaining 40 per cent comes from various areas such as South Texas, nine per cent; East and East Central

BIG INCH PIPE LINES like this link Texas' many oil fields to Houston's refineries.

Texas, 18 per cent: Panhandle and North Texas, eight per cent; and Louisiana, five per cent.

Of the 900,000 bbl of crude delivered to Houston daily, about 15 per cent comes in by barge, tanker, or railroad tank car. The remaining 85 per cent comes in through a system of pipe lines which reach into the various oil producing areas of the state (see map) and provide a constant flow of oil from thousands of individual wells to central pipe line pump stations, thence to the great Houston refining center. The principal pipe lines serving this area and their typical daily pumping rates are as follows:

Company	Bbl Daily	Source of Crude
Humble	95,000	Panhandle and West Central Texas
	145,000	Gulf Coast
	135,000	West Texas-New Mexico
Pan American	45,000	Gulf Coast
	40,000	East and East Central Texas
Service	40,000	West Central Texas
Sinclair	75,000	West Central Texas
	16,000	Gulf Coast
Shell	30,000	East and East Central Texas
	13,000	Gulf Coast
	36,000	West Texas
Texas	25,000	Gulf Coast
Texas-New Mexico	67,000	West Texas-New Mexico
Total	762,000	

Ever mindful of the increasing demand for petroleum products, pipe line companies are constantly increasing the capacities of these pipe lines and are building new lines to the prolific oil producing areas. The latest of these is the 24-in. (diameter) Rancho Pipe Line System which is jointly owned by seven pipe line companies and is now under construction. It will bring in initially 200,000 B/D of crude oil from the fields of West Texas and New Mexico to feed the thirsty refineries of the Houston area.

Refineries

As indicated earlier, Houston is perhaps the world's greatest refining center. The accompanying map and chart shows locations, capacities and types of refineries in the Houston area and a typical flow diagram of one of the largest of these refineries. At least three of these plants are complete refineries capable of manufacturing almost every type and quality of petroleum product; the others have a lesser number of processing units and are somewhat more limited in the diversity of their refined oil output.

The kind and quality of the products which these refineries manufacture are ever changing. Refiners fit their operations to the demands of the consuming public as well as the requirements for national defense. For example, a relatively new but important product now being manufactured in undisclosed amounts is jet aircraft fuel. Then, too, the refineries change their production seasonally to provide the increased quantity of gasoline needed for summer vacation time, and the increased requirements for heating oil in the winter. Typically, however, the refineries in the Houston area produce the following products:

325,000	B/D of gasoline
60,000	B/D of kerosene and jet fuel
160,000	B/D of distillate fuel oil
180,000	B/D of residual fuel oil
25,000	B/D of lubricating oil
30,000	B/D of asphalt
10,000	B/D of coke
30,000	B/D of other products
820,000	B/D Total

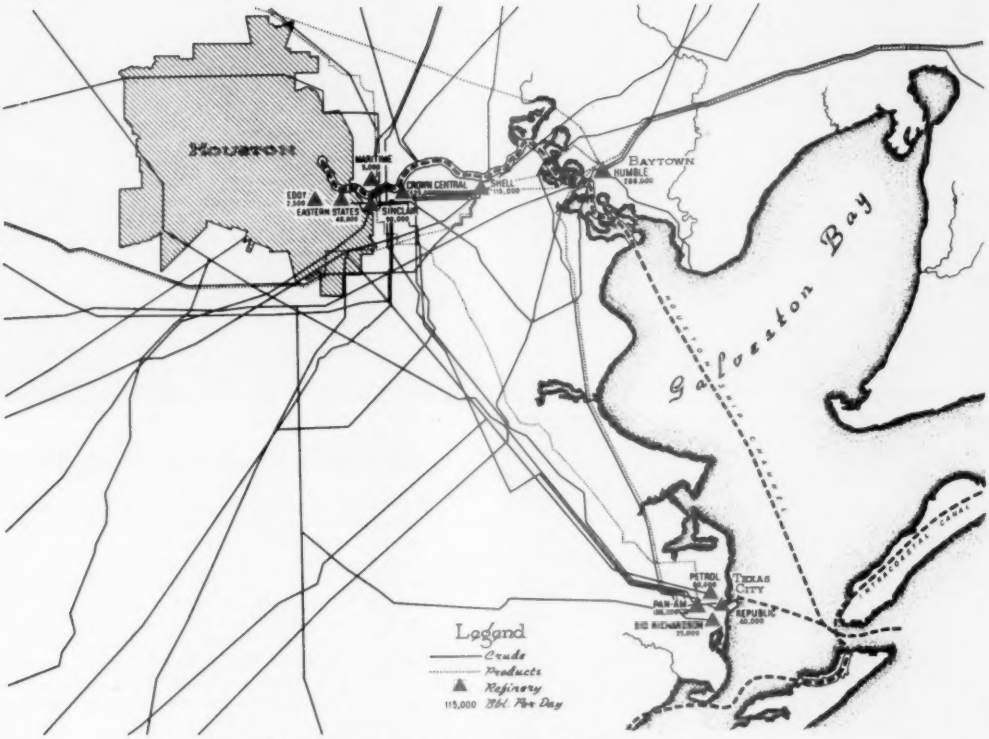
Among the "other products" manufactured are numerous items including naphthas for paint, lighter fluid, sulphur, fluids and materials used by the chemical industries to make such things as synthetic rubber, plastics, fertilizer, insect sprays, and even medicines.

The total value of these refined products coming from the

Houston Area Refineries

(Capacity, B/D)

Company and Type	Crude-Oil Charge	Thermal Cracking Capacity	Catalytic Cracking Capacity	Type Refinery
Crown Central Pet. Corp.	25,000	9,200	17,500	Skimming-Cracking-Lube
Eastern States Pet. Co., Inc.	48,000	22,000	23,500	Skimming-Cracking
Eddy Refining Co.	2,500			Skimming
Humble Oil and Refining Co.	286,000	79,000	101,000	Complete
Maritime Oil Co.	5,000			Skimming
Pan American Refining Co.	130,000	6,500	32,000	Skimming-Cracking
Petrol Refining, Inc.	60,000		11,000	Skimming-Cracking
Republic Oil Refining Co.	40,000	10,000	15,000	Skimming-Cracking
Shell Oil Co.	115,000	46,000	33,500	Complete
Sid Richardson Refining Co.	25,000	20,000		Skimming-Cracking
Sinclair Refining Co.	90,000	30,000	22,000	Complete



Houston - Texas City Refineries and Feeding Pipe Lines

immediate Houston area has been placed at $2.665.000 per day or almost one billion dollars per year.

Products Distribution

About 93,000 B/D of the area's refined products move out by products pipe line. The Bayou Pipe line System takes 50,000 bbl eastward to Baton Rouge, La., where it joins the Plantation Pipe Line to supply the southeastern states. Two other products lines transport 43,000 bbl northward to the populous Dallas-Fort Worth area.

But by far the Gulf Coast's largest customer is the eastern states. While the population of the New England, Middle Atlantic and South Atlantic states represents 40 per cent of the nation's total, the oil refining capacity of those same sections amounts to only 16 per cent of the United States' total. It is obvious, then, that this region must import from other sections a large percentage of its refined petroleum products. And the area best situated, both geographically and economically, to provide these products is the Gulf Coast, with its large percentage of refining facilities (32 per cent of the nation's total) and its smaller population.

At present, the Bayou pipeline and the connecting Plantation pipeline provide the only through transportation of products to the Eastern states directly from the Gulf Coast and the latter extends only as far northeastward as Greensboro, N. C. Of necessity, then, the burden of transporting the major portion of the Gulf Coast's products falls to ocean-going tankers and barges, just as the job of gathering crude oil has fallen mainly to the pipe lines.

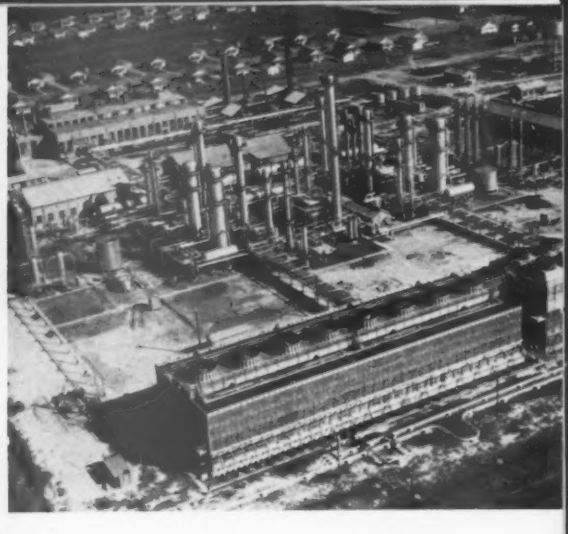
The following table which lists approximate amounts and destinations of refined products moving out of the Houston area during recent months gives an indication of the scope of the waterborne traffic and makes it apparent that the East Coast receives a very large percentage of all petroleum products exported from the Gulf Coast refining centers:

East Coast	463,000 B/D
Gulf Coast	88,000 B/D
Pacific Coast	4,000 B/D
Foreign	85,000 B/D
Internal	70,000 B/D

The "internal" movement of products consists mainly of traffic by barges up the Mississippi river and other inland waterways; any movement to the Pacific Coast is an unusual occurrence occasioned by an exceptional demand on the West Coast.

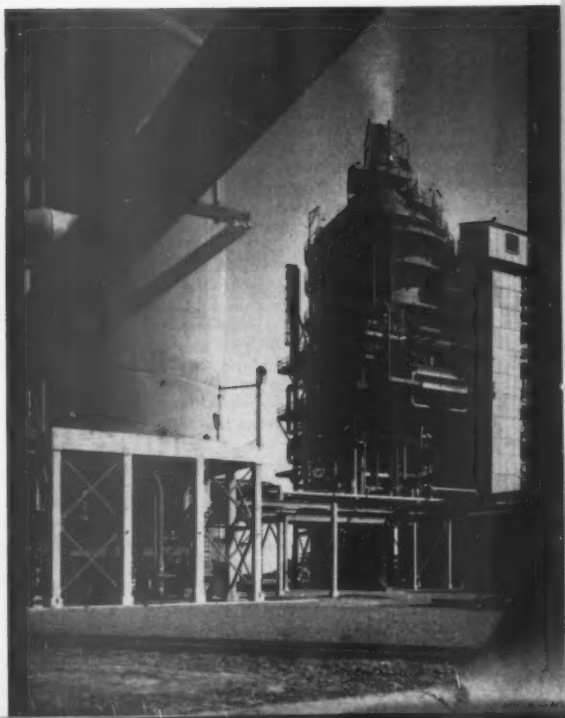
There seems to be no end in sight to this orderly growth of prosperity of Houston and the Texas Gulf Coast. Each year brings the discovery of larger and larger reserves of crude oil in the Southwest. More and more automobiles are rolling on the nation's highways. And more and more homes are being constructed which require heating fuels. Petro-chemical plants utilizing refinery "waste products" as raw materials, are springing up throughout the area, bringing, in turn, more workers and payrolls.

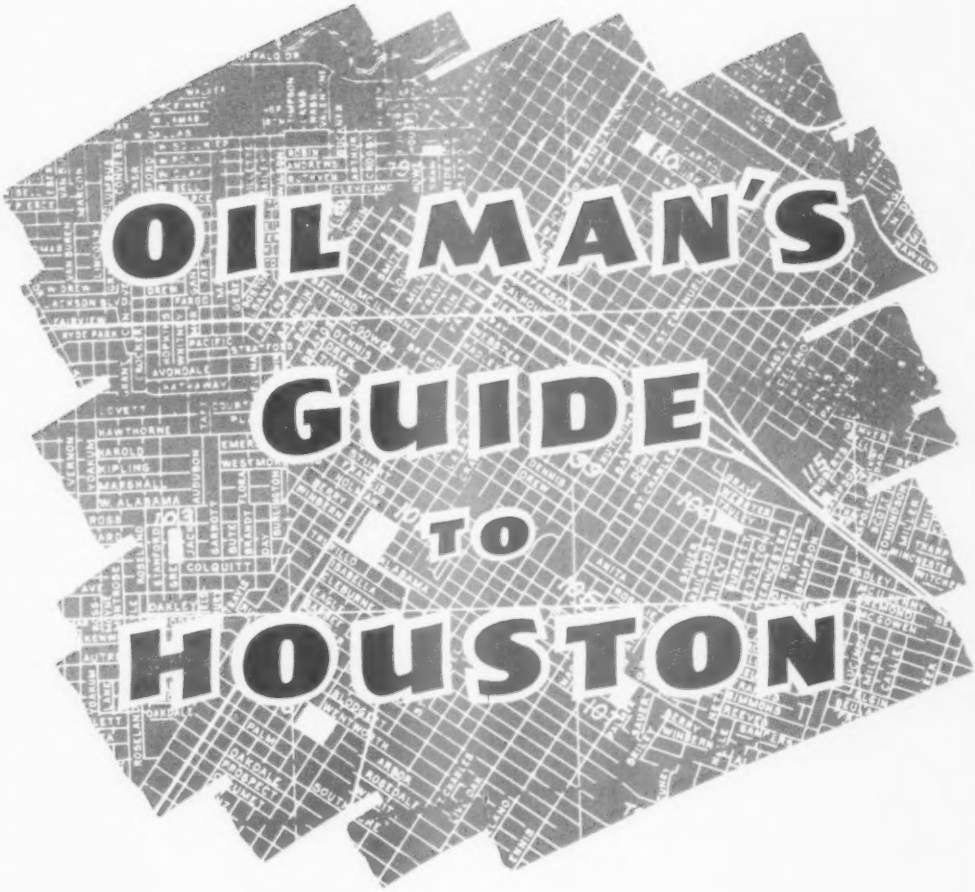
Houston calls herself "America's Industrial Frontier" and this frontier is being broadened daily by the men of the industry whose energy indeed moves a nation.



Houston Processing Facilities

Processing and refinery layouts dot the area surrounding Houston making it one of the important centers of such activity in the United States. At upper left is a view of Humble's Baytown refinery which processes an average of some 250,000 B/D. At left is the Clear Lake Gas Plant which processes casinghead and gas well gas. At bottom left is the Turning Basin of Houston's ship channel. Above is the Katy Cycling plant and below is Shell Oil Co.'s newest catalytic cracking unit at their Houston refinery. High as a 16-story building, this "cat cracker" processes 22,000 B/D of petroleum products such as aviation and automotive gasolines, fuel oils and light fractions.





Courtesy of

HOMCO

HOUSTON OIL FIELD MATERIAL COMPANY, Inc.

HOUSTON, TEXAS

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31 SHELL BLDG
9 SOUTHERN PACIFIC OFFICE BLDG
1 SOUTHERN PACIFIC PASSENGER STATION
15 SOUTH TEXAS NATIONAL BANK
29 SOUTHWESTERN BELL TELEPHONE BLDG
13 STATE NATIONAL BLDG
32 STERLING BLDG
19 STEWART BLDG
28 TEXAS COMPANY BLDG
47 TEXAS STATE HOTEL
5 UNION NATIONAL BANK
10 UNITED GAS BLDG
25 UNITED STATES POST OFFICE
30 WESTERN UNION BLDG

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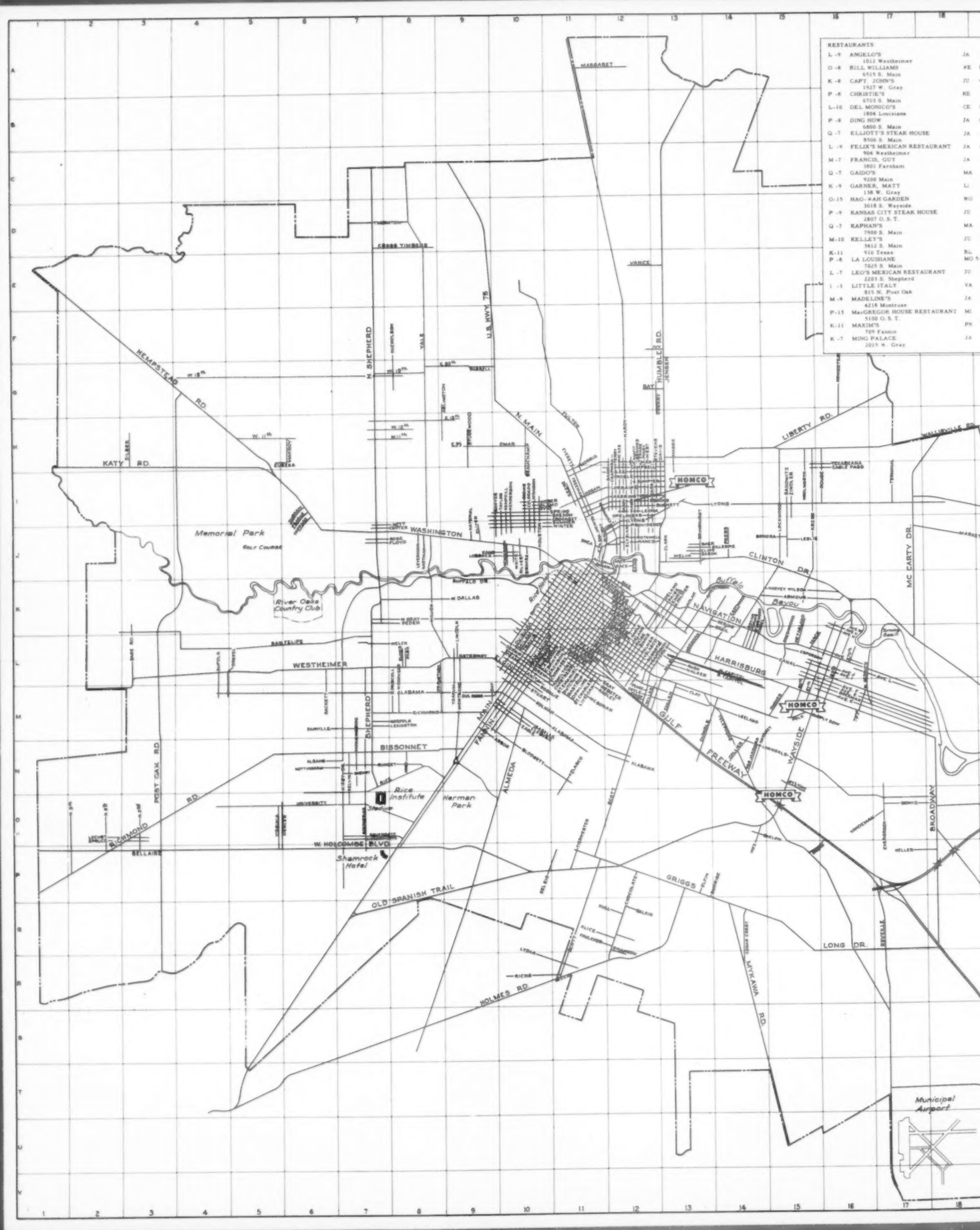
CAROLINE
LAMAR
AUSTIN
SAN JACINTO
DALLAS



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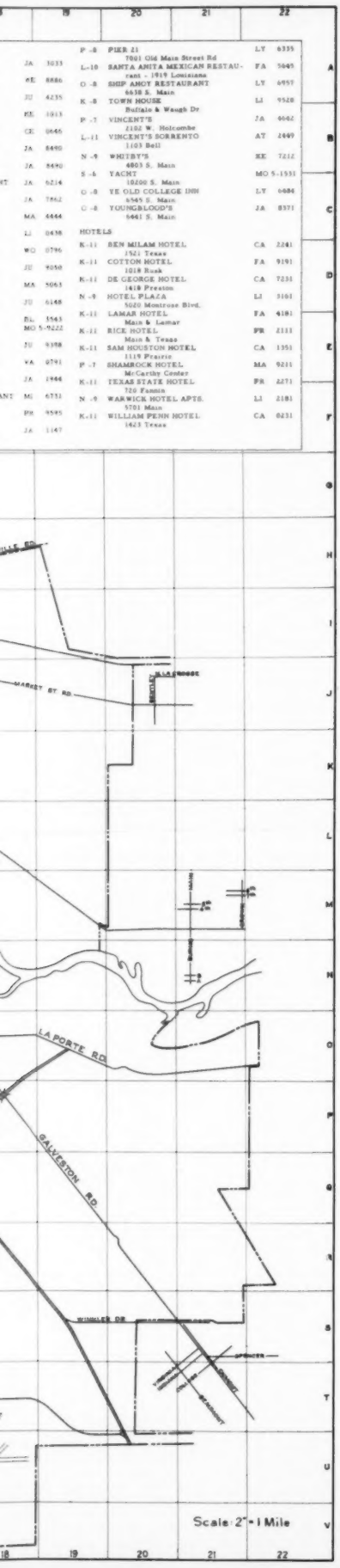

GUIDE TO OIL FIELD SUPPLY, SERVICE AND MANUFACTURING ORGANIZATIONS

*A-1 BIT & TOOL CO 9000 Almeda LY 3831
P-14 API WELL SERVICE 5010 Griggs MI 8220
I-42 ABEGG & REINHOLD CO 1502 Maury CH 3579
Q-12 ACORD TOOL & SUPPLY, INC 5005 Holmes Rd OL 2636
M-10 ALLEGHENY LUDLUM STEEL Corp - 4101 San Jacinto KE 5526
K-11 ALLIS-CHALMERS MFG CO 1719 McKinney PR 7188
K-14 ALLIS, LOUIS CO 4411 Navigation BL 6661
H-12 AMERICAN BRAKE SHOE CO 2602 Maury PR 4733
L-15 AMERICAN CHAIN & CABLE CO, Inc. - 630 McFarland WO 6435
M-12 AMERICAN GEAR & SUPPLY CO, 3438 Leeland AT 5293
H-4 AMERICAN INDUSTRIAL FABRICators, Inc - 7120 Katy Hwy TW 1661
I-42 AMERICAN IRON & MACHINE works Co - 1001 Semmes FA 6305
K-11 AMERICAN PACKING & GASKET Co - 1115 Austin - Box 213 CH 1794
H-17 AMERICAN STEAM PUMP CO 7700 Wallisville Rd OR 7570
M-20 AMERICAN STEEL & WIRE CO Clinton Dr OR 1681
I-42 ARIZONA BARITE CO 1524 Maury CH 6601
L-10 ARMSTRONG STEAM TRAP CO 2204 Fannin FA 8468
I-42 ASSOCIATED OIL FIELD RENTALS Inc - 1819 Semmes CA 9596
I-11 ATLAS ENGINEERING WORKS 1406 Jefferson AT 8456
O-18 B & W INCORPORATED 1020 Fennell - Box 5266 WE 6603
J-15 BAASH-ROSS TOOL CO 5306 Clinton Dr OR 1721
L-15 BAKER OIL TOOLS, INC 6023 Navigation Blvd OR 9351
J-9 BARADA & PAGE, INC 2812 Center - Box 7568 PR 6135
M-7 BAROID SALES DIVISION NATIONAL Lead Co - 2404 Dixville LI 6381
H-4 BASEN STEEL WORKS 7510 Katy Rd UN 3175
J-10 BEACON SUPPLY CO, INC 1825 Washington CA 1397
K-11 BEARD & STONE ELECTRIC CO 805 Polk FA 6191
L-11 BEAUMONT IRON WORKS CO 1406 Jefferson CA 0275
I-12 BERENTZ, ROT A CO, INC 1400 Carr CH 6558
K-16 BETHLEHEM STEEL CO 7100 Clinton Dr OR 7411
K-16 BETHLEHEM SUPPLY CO 7100 Clinton Dr OR 7411
L-15 BETTIS CORPORATION 320 S 66th St YU 5401
T-5 BLACK, SIVALLS & BRYSON, INC 11515 Main MO 3629
P-14 BOENCK ENGINEERING CO, INC 5806 Long Drive OL 6331
I-9 BOWEN CO OF TEXAS, INC 6429 Crockett AT 4566
Q-11 BOWEN OIL WELL SERVICE 7030 Eastwood MI 6778
J-12 BRAGG ENGINEERING CO, INC 224 Rains FA 8367
K-11 BRIDGEPORT BRASS CO 1220 Polk CH 5511
M-16 BRIGGS-WEAVER MACHINERY Co - 300 S Wayside TU 3561
J-19 BRODERICK & BASCOM ROPE CO 9350 Market St Rd OR 6633
I-12 BROWN OIL TOOLS, INC 2216 Campbell FA 1343
*BROWN OIL TOOL, INC 8490 Katy Rd HO 5-2501
J-12 BROWN WELL SERVICE 2216 Campbell FA 1343
K-12 BROWNING-FERRIS MACHINERY Co - 2619 Texas BL 3231
M-16 BUDA ENGINE & EQUIPMENT CO 6616 Harrisburg YU 3337
L-15 BYRON JACKSON CO 6247 Navigation WO 8321
H-3 CAMERON IRON WORKS Silber Road VI 4611
J-15 CHICAGO BRIDGE & IRON CO 5625 Clinton Dr CE 7625
M-12 CLARK OIL TOOL CO 1304 Hays FA 7868
J-15 CLECO DRY-REED ROLLER BIT CO 5125 Clinton Dr OR 1761
J-12 COASTAL SUPPLY CO 1121 Rothwell - Box 1294 CE 8055
O-5 COCHRAN-DEAN DIRECTIONAL Drilling Co - 6615 Mercer MO 2206
G-8 COCHRAN EQUIPMENT CO 1722 ORT JU 2222
L-15 COLORADO FUEL & IRON CORP 340 South 66th - Box 9367 WO 1776
L-13 COLUMBIAN STEEL TANK CO 3705 McKinney FA 7261
L-15 CONTINENTAL SUPPLY CO 6001 Navigation Blvd FA 4619
J-12 COOPER, FRED E INC 1618 Franklin AT 3401
M-25 CORBERT, JOE DIRECTIONAL DRG 400 Wayside WE 2680
I-9 CORBETT CORP THE 2451 Summer - Box 42 AT 5385
K-15 CORE LABORATORIES INC 5700 Navigation Blvd WO 6621
L-12 CRANE CO 2204 Peace CE 8811
M-15 CRANE PACKING CO 6626 Supply Row WE 7683
K-15 CRUCIBLE STEEL CO - DISTR 6416 Navigation Blvd WA 7113
H-2 CRUTCHER-ROLFS-CUMMINGS 7825 Katy Road VI 6391
S-8 CULP ENGINEERING CO 2400 Holmes Rd JU 5525
K-15 CUMMINS SALES & SERVICE INC 6230 Navigation Blvd WO 8831
M-14 CUNNINGHAM, W P CO 4913 Leeland WO 1795
H-18 DAILY OIL TOOLS, INC 125 McCarty OR 2521
J-15 DANIEL ORIFICE FITTING CO 5805 Clinton Dr OR 2516
O-15 DANNENBAUM, M N CO 2461 S Wayside WO 2674
I-11 DEE BRASS FOUNDRY 2408 Everett - Box 8627 CA 6271
J-17 DEWEY SUPPLY CO 1000 McCarty OR 8381
P-11 DIA-LOG CO, THE 5330 Old Spanish Trail JU 4191
*DIAMOND ALKALI CO Deer Park GR 5-2301
M-16 DIRECTIONAL DRILLING Specialists - 400 Wayside WE 2488
L-13 DIXIE CHEMICAL CO 718 N Drennan AT 1487
I-10 DRESSER EQUIPMENT CO Ideco Div - 1619 Ovid AT 2351
I-12 DRESSER MFG DIV 1121 Rothwell (Section 16) CH 4723
P-8 EASTMAN OIL WELL SURVEY CO 1710 Old Spanish Trail LY 9155
L-12 EDWARDS, E N CO 1208 Velasco FA 5436
M-6 ELECTRONICS ENGINEERING, INC 2708 Suffolk Dr MA 1453
L-13 EMPIRE STEEL CO 1400 Cullen BL 3531
T-16 EMSCO DERRICK & EQUIPMENT Co - Garden Villas - Box 1289 MI 3361
I-12 EMSCO SCREEN PIPE CO 2219 Brooks - Box 1261 PR 6346
H-5 ENGINEERS & FABRICATORS, INC 3501 W 11th VA 6646
L-12 EVERETT & SON 5325 McKinney Ave CH 0656
E-15 EXNER-DODGE, INC 5710 Harvey Wilson WE 9313
M-13 FAILING, GEO E SUPPLY CO 3611 Calhoun - Box 1638 PR 7225
E-15 FAIRBANKS-MORSE & CO 5521 Navigation Blvd WA 2159
M-15 FALCON PRODUCTS, INC 320 S 86 YU 1146
H-11 FITLER, EDWIN H CO 1201 Commerce St CE 7610
L-15 FLUID PACKED PUMP CO 6229 Navigation Blvd HA 7101
H-14 FOX RIG & LUMBER CO 5336 Lawndale WO 8364
Q-15 FRANKS MFG CORP 6606 Long Drive OL 8961
Q-17 FRUEHAUF TRAILER CO 2305 Broadway MI 6641
M-9 GAMMA INSTRUMENT CO 5521 Navigation Blvd LY 2379
L-12 GARDNER-DENVER CO 2201 Polk PR 9295
N-6 GARRETT OIL TOOLS, INC 2600 Nottingham MA 0491
L-12 GARROTT BRASS & MACHINE Co, Inc - 1718 Ennis FA 0346
N-21 GAS GIL RATIO CONTROL CO 1806 5th OS 4-0982
M-12 GATES RUBBER CO SALES DIV, Inc - 110 Milby CA 9177
M-15 GEARENCH MFG CO 317 Hughes WA 6188
L-12 GENERAL ELECTRIC CO 1312 Live Oak BL 0261
L-13 GENERAL MANUFACTURING CO 1515 Main AT 6646
G-16 GENERAL METALS CORP Liberty Rd - Box 198 OR 1775
L-14 GEOLOGRAPH GULF COAST Service Co - 5417 Harrisburg WO 6288
I-17 GEORGE RENTAL SERVICE CO 773 McCarty - Box 1261 OR 1747
Q-14 GLOBE MACHINE & NIPPLE CO 4020 Cedar Crest MI 2479
H-7 GOODALL RUBBER CO OF TEXAS 3550 W 12 VI 2691
M-15 GRAY TOOL CO 6102 Harrisburg WA 2111
I-12 GUIBERSON CORP, THE 1602 Maury CH 8305
M-13 GULF ENGINEERING CO, INC 1602 Ingeborg PR 7251
H-6 GULF TRACTOR & EQUIPMENT CO 9946 Katy Rd VI 6471
K-15 GUSTIN-BACON MFG CO 5531 Armour Dr WO 2671
J-15 HAMM & CLAY 5100 Clinton OR 1671
L-13 HALLIBURTON OIL WELL CEMENTING Co - 727 N. Drennan AT 6405
P-8 1628 Old Spanish Trail LI 2161
K-12 HAMILTON RUBBER MFG CORP 2017 Preston Ave CE 7351
J-12 HARRISBURG SALES & SERVICE 1316 Conti CA 1211
M-15 HARRISON CHEMICAL CO, THE 6622 Supply Row WE 1627
L-15 HAZARD WIRE ROPE DIV OF American Chain & Cable Co, Inc - 630 McFarland WO 6435
Q-12 HENSLEY, TOM PARAFFIN Cleaning & Swabbing Service - 6500 Swanson - Box 16021 OL 2811
L-16 HERCULES MOTORS CORP 6018 Navigation Blvd WO 9435
K-16 HERCULES SUPPLY CO 6900 Clinton Dr WO 8386
L-12 HEWITT RUBBER DIV 1108 Velasco CE 9351
R-12 HINDERLITER TOOL CO, DIV of H K Porter Co, Inc 5018 Griggs Road MI 6633
WO 2656
K-12 HOBBS MFG CO 6510 Navigation Blvd PR 2176
K-12 HOUSTON ARMATURE WORKS 2301 Preston Ave PR 6188
L-12 HOUSTON ENGINEERS, INC 1412 Ennis FA 7131
M-10 HOUSTON GAMMA RAY CO 103 W Alabama JA 2962
I-12 HOUSTON OIL FIELD MATERIAL Co, Inc - 1526 Maury CH 6661
M-15 500 S Wayside WO 7888
O-15 2101 S Wayside WO 1731
L-15 HUGHES TOOL COMPANY 5425 Polk Ave - Box 2539 WO 3101
M-13 HUNT TOOL CO 1945 Cullen - Box 1436 FA 7131
K-16 HUTCHISON MFG CO, INC 6609 Ave "U" - Box 9335 WO 7671
*NYDRILL CO Beaumont Hwy OR 7533
I-10 INTERNATIONAL DERRICK & Equipment Co - 1619 Ovid - Box 1653 AT 2351
L-12 JARECKI INTERNATIONAL SUPPLY Div of H K Porter Co, Inc 2201 Walker FA 0706
L-8 JOHNSON, M S 1735 Westheimer KE 7311
L-15 JOHNSTON TESTERS, INC 5702 Navigation Blvd - Box 165 WO 6695
I-12 JONES & LAUGHLIN SUPPLY CO 2210 Quitman CA 0551
M-6 K & G OIL TOOL & SERVICE, INC 2703 Sackett JA 5436
N-6 K & K CONTRACTORS 5402 Kirby Drive - Box 6617 MA 0470
Q-9 KERN DIRECTIONAL DRILLING Corp - 1847 Old Spanish Trail KE 6123
N-6 KEYSTONE TOOL CORP 5525 Kirby Dr KE 1623
L-16 KIDD CO, THE 6837 W YU 2624
L-3 KINLEY, M M CO Sage Rd - Box 13206 MO 4501
J-9 KINZBACH TOOL CO 2411 Summer - Box 277 CA 9456
Q-15 KREITER GEAR & MACHINE, INC 6618 Long Dr FA 6551
I-12 L & H MACHINE WORKS 2205 Quitman CH 2581
L-16 L K PUMP VALVE CO 652 N Edgewood WE 3003
I-10 LAMBERT CO 1818 Weber - Box 151 CH 0616
L-13 LAMONS, W A MANUFACTURER 3600 Canal - Box 947 CH 8195
N-15 LANE-WELLS CO 2002 S Wayside WO 1701
I-12 LARKIN PACKER CO, INC 1502 Maury CH 2677
J-17 LAYNE & BOWLER CO 7800 Market St Rd - Box 1327 OR 7563
N-16 LAYNE-TEXAS CO., LTD. THE 5402 Lawndale WE 7003
H-5 LINCOLN ELECTRIC CO 3602 W 11 VI 7701
M-15 LINDE AIR PRODUCTS CO, THE 6119 Harrisburg WO 5165
Q-15 LINK-BELT CO 3203 S Wayside WE 5581
J-12 LLOYD METAL FOUNDRY CO 1320 Carr PR 5325
L-16 LONGHORN MACHINE WORKS 6823 Navigation Blvd WE 2886
K-13 LONGHORN SUPPLY CO 3130 Navigation Blvd BL 0611
I-16 LOWREY OIL TOOLS, INC 7306 Laredo OR 8661
I-17 McCULLOUGH TOOL CO 405 McCarty OR 2661
L-13 McEVOY CO 600 Milby CH 7801
M-12 McFARLAND MFG CORP 1630 Roberts FA 7165
S-9 M & R SPECIALTY CO, INC 4500 Heimer LY 2666
Q-15 MAGNAFLUX CORP 2005 S Wayside WE 0068
Q-3 MAGNET COVE BARIUM CORP 5001 Richmond Rd MO 6571
J-11 MARSH INSTRUMENT CO 1121 Rothwell CH 2393
J-14 MATTCO SLUSH PUMP CO 621 N Edgewood WO 2611
Q-17 MAXWELL BAILER CORP 6929 Vanderman WA 6476
Q-14 6114 Long Drive OL 4281
I-12 MERCER RUBBER CO 1601 Maury PR 0149
L-13 METAL GOODS CORP 714 Milby CE 8881
L-15 MID-CONTINENT SUPPLY CO 4220 Navigation Blvd WO 1781
I-15 MILWHITE MUD SALES 5800 Lyons OR 7521
Q-14 MINNEAPOLIS-HONEYWELL Regulator Co - 5440 Gulf Freeway TU 2451
G-15 MISSION MFG CO 5200 Humble Rd MU 5561
J-8 MOSHER STEEL CO 3910 Washington UN 8181
L-13 MURRAY RUBBER CO 1010 N Milby CH 7651
B-10 NATIONAL FLAME TREATING CO 330 W 25 UN 8169
K-15 NATIONAL STEEL PRODUCTS CO 7501 Lockwood Drive TU 5481
L-15 NATIONAL SUPPLY CO 6229 Navigation WA 7101
L-13 NATIONAL TANK CO 3610 McKinney PR 6208
K-13 NILAND, TOM EQUIPMENT CO 11 N Hutcheson CH 6703
L-12 NORDSTROM VALVE DIV Rockwell Mfg Co - 1102 Delano AT 6601
J-12 NORRIS, W C MFG INC 1125 Rothwell BL 0141
K-6 NORVELL-SERVICE CO Memorial Drive MO 5-2321
J-12 NORVELL-WILDER SUPPLY CO 1502 Maury AT 3471
J-12 O-T-M CO 118 Nance CA 7293
G-9 OIL CENTER TOOL CO 1912 Airline UN 8191
L-15 OILFIELD MACHINE & SUPPLY CO 6418 Epperson St WO 4058
I-12 OILFIELD SALVAGE CO, INC 6619 Brooks CH 6916
K-12 OIL WELL MANUFACTURING CORP 2301 Commerce PR 6496
J-12 OIL WELL SUPPLY DIVISION - U. S. Steel Co - 1119 Rothwell AT 9361
I-9 OTECO EQUIPMENT CO 2430 Summer CH 1847
P-15 OTIS PRESSURE CONTROL, INC 2402 Broad OL 8525
I-10 PACIFIC PUMPS, INC 1619 Ovid AT 2351
K-15 PACIFIC WIRE ROPE CO 6001 Clinton Dr WE 5525
J-12 PARIS, HENRY H DISTRIBUTOR, 500 S Wayside Rothwell BL 0141
H-5 PARKERSBURG RIG & REEL CO, The - 6716 Eureka VI 6695
K-13 PATTCO CO, INC 3125 Navigation CE 9496
L-15 PATTERSON-BALLAGH, DIV OF Byron Jackson Co - 6247 Navigation WO 8321
J-11 PEDEN IRON & STEEL CO 700 N San Jacinto CA 2121
R-11 PERFORATING GUNS ATLAS CORP 7750 Bonhill LY 4161
M-12 5915 Tharp PR 4351
I-11 PIONEER WELL TOOLS, INC 614 Hogan FA 4748
K-13 PLOWDEN SUPPLY CO 3201 Navigation Blvd CA 0121
L-16 PORT HOUSTON IRON WORKS, INC 7222 S Harbor Dr WO 9601
J-11 PRODUCERS SUPPLY & TOOL CO 1121 Rothwell PR 6109
K-12 RECTOR WELL EQUIPMENT CO, Inc - 2215 Commerce CA 6168
L-15 REED ROLLER BIT CO 6501 Navigation Blvd WO 3121
L-16 REPUBLIC DRILL & TOOL CO 6819 "B" KE 1402
K-13 REPUBLIC SUPPLY CO 906 Middle AT 8617
J-15 RHEEM MFG CO 1025 Lockwood Dr CH 1611
L-10 RIG-A-LITE CO, THE 2507 Smith JA 2907
K-13 RUSSEL, C A, INC 15 N Drennan St CH 6021
L-12 SCHLUMBERGER WELL SURVEYING Corp - 2700 Leeland CA 9311
Q-16 SCHLUMBERGER WELL SURVEYING Corp - 9930 Long Dr MI 3331
L-15 SHAFFER TOOL WORKS 6008 Navigation Blvd WO 1795
*SHEFFIELD STEEL CORP Industrial Rd GL 5-7221
*SMITH, A O CORP Industrial Rd GL 5-7221
M-5 SMITH, NOWERY J CO 8000 Hempstead Rd UN 8211
*SOUTHERN TEXAS BAILER & SUPPLY Co - 9900 Telephone OL 2091
L-15 SOUTH TEXAS EQUIPMENT CO 5500 Navigation Blvd TU 2466
L-12 SOUTHERN ENGINE & PUMP CO 900 St Charles - Box 1697 CA 9278
L-15 SOUTHWELL SUPPLY CO 3828 Polk CA 9140
K-14 SOUTHWEST CO, THE 615 N Edgewood WA 7805
M-11 SPERRY-SUN WELL SURVEYING Co - 5118 Blodgett KE 8166
L-15 STANCO CO, THE 5646 Navigation WE 4695
J-13 STANDCO BOLT CO 2701 Clinton Dr OR 5565
J-13 STANDCO BRAKE LINING CO Mfrs - 2701 Clinton Dr FA 5566
L-12 STAYTITE CO 3608 Polk FA 4358
L-15 STEEL & MACHINE TOOL SALES CO 6416 Navigation Blvd HA 7113
L-12 STEIGERWALD, W H CO, INC 2119 Dallas PR 8106
K-13 STENZEL PATTERN WORKS 5536 Navigation Blvd PR 0809
Q-12 STEWART CASING CREW Service - 6501 Chocolate Bayou Rd OL 0951
L-16 STEWART & STEVENSON SERVICES Inc - 4515 Harrisburg WO 9801
L-16 SUPERIOR IRON WORKS & SUPPLY Co, Inc - 6917 Navigation WE 3671
M-21 TECHNICAL OIL TOOL CORP, Ltd - 2609 5th OS 4-1653
J-13 TEXAS ELECTRIC STEEL CASTING Co, Inc - Broughton & Gillespie BL 6363
I-12 TEXAS IRON WORKS 1425 Maury CH 0671
E-13 TEXAS RUBBER & SPECIALTY Corp - 930 Adele UN 6101
J-11 TEXAS SCREW PRODUCTS CO 715 Bromks AT 6505
M-15 TEXASTEAM CORP 320 Hughes WO 2855
J-9 TEX-TUBE, INC 1504 Oliver CH 5411
L-13 THERMOD CO 14 Kendall FA 4357
J-15 THORNHILL-CRAVER CO 1111 Lockwood Dr CH 1661
O-15 TRET-O-LITE CO 3202 S Wayside WO 2457
K-13 TRINITY PORTLAND CEMENT DIV of General Portland Cement Co - 3515 Navigation Blvd PR 9191
S-9 TUBOSCOPE CO 2400 Holmes Rd JU 2577
J-10 TURBOLITE CO 1020 Houston CH 1049
*UNION TANK & SUPPLY CO 12701 Almeda - Box 2092 JU 9681
K-13 UNION WIRE ROPE CO 5229 Navigation AT 4367
M-7 UNITED CORE, INC 3816 S Shepherd JU 0687
E-7 UNIVERSAL ENGINEERING CO 4927 N Shepherd ME 1510
K-12 UNIVERSAL OIL TOOL CO 2005 Crawford FA 3751
K-15 UNIVERSAL PACKING & GASKET CO 5219 Clinton Dr OR 8321
K-13 W-K-M CO 221 Roberts PR 9211
L-11 WAHLBERT-McGREARY, INC 1608 Caroline CH 3531
L-11 WALKER, T L, CO 1619 Carolina CH 6566
L-12 WALL ROPE WORKS, INC 815 Live Oak FA 8080
K-16 WALLACE CO 6985 Clinton Dr WE 2831
J-12 WAUKESHA SALES & SERVICE, INC 1602 Maury - Box 16036 AT 9861
J-7 WEBER IRON & WIRE CO 4819 Floyd UN 0838
J-12 WEISE STRAINER & MFG CO 812 Walnut PR 5151
P-10 WELEX JET SERVICES, INC 6512 Del Rio LI 7581
I-12 WELL EQUIPMENT MFG CORP 2023 Semmes CA 1321
P-2 WELL PERFORATORS, INC 5818 Old Richmond Rd MO 4631
J-12 WESTERN WELL SCREEN CO 812 Walnut PR 5151
J-15 WHITE NIPPLE MACHINE CO 1140 Lockwood CH 6565
M-15 WICKWIRE SPENCER STEEL DIV Of The Colorado Fuel & Iron Corp - 300 S 66 WO 1776
J-12 WILLIS OIL TOOL CO 1212 Nance PR 8853
J-12 WILSON FOUNDRY & MACHINE CO 1417 Elerson FA 7356
M-16 WILSON, R L CO, INC 6707 Texarkana OS 5-6872
J-12 WILSON SUPPLY CO 1301 Conti CA 0471
H-5 WYATT METAL & BOILER WORKS Washington-M K T Tracks UN 3161
D-8 YALE MACHINE WORKS 6403 Yale ME 4281
D-7 ZUBLIN BIT CO 6527 N Shepherd ME 3611

This map shows a representative group of Houston's Oil Field Service, Supply and Manufacturing Organizations. It does not show any downtown offices, plants outside the city limits or organizations which do not have plants or major warehouses directly serving the oil drilling industry in Houston. In order to simplify the map the only streets shown are those necessary to locate the companies listed.

Inasmuch as this guide map does not show all the city streets, please call the HOMCO operator at WO-1731 for complete directions to any point.

Listings Courtesy of the Oil and Gas Directory, Houston

Meet HOMCO

HOUSTON OIL FIELD MATERIAL CO., Inc.

in HOUSTON

MANUFACTURING AND SERVICE DIVISION
2101 South Wayside Drive

HOMCO Manufacturing Division consists of the Manufacturing Department and the Service and Rental Department. The Manufacturing Department makes many oil field tools for outright sale through the HOMCO Sales Division. The Service and Rental Department offers technical trouble-shooting service to drilling operators for cutting and fishing operations, directional drilling, pressure welding, sidewall coring, and well surveying.

GENERAL OFFICE AND SALES DIVISION
1534 Maury St.

This is the hub of activity for all of HOMCO's outpost stores and sales activities. HOMCO Supply Stores offer the Oil Industry's most complete stocks of oilfield supplies in 16 locations in the active drilling areas.

MUD AND CHEMICAL DIVISION
300 South Wayside Drive

HOMCO offers the most complete stocks of drilling muds and chemicals in the industry. Products of all leading mud and chemical producers are handled, including Arizona Barite Co., which is a HOMCO subsidiary.

HOMCO SUPPLY, SERVICE, AND SALES POINTS

S indicates supply store F indicates service point
R indicates sales office

TEXAS: S, F, Houston; S, F, Odessa; S, F, Snyder; S, San Angelo; S, Beaumont; S, F, Corpus Christi; S, F, Victoria; S, Bay City; S, Kenedy; S, F, Alice; S, Freer; S, Sam Fordyce; R, Fort Worth; F, R, Midland (Service Division Office); R, Dallas; R, San Antonio; F, Edinburg.
LOUISIANA: S, F, Harvey; S, F, Houma; S, F, New Iberia; S, F, Lake Charles; F, R, New Orleans (Service Division Office).
OKLAHOMA: R, Tulsa.
CALIFORNIA: F, Long Beach; F, Bakersfield; F, Ventura.
WYOMING: F, R, Casper.
MISSISSIPPI: F, Brookhaven.
NEW MEXICO: F, Farmington; F, Hobbs.
COLORADO: R, Denver.

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Accuracy and dependability are assured by the exclusive design and precision manufacture of these instruments. If you're not acquainted with these points of superiority, ask the Sperry-Sun representative about them the next time he's around.

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SPERRY-SUN WELL SURVEYING COMPANY

3118 BLODGETT AVENUE HOUSTON, TEXAS

Philadelphia, Pa. Falfurrias, Odessa, Marshall, Texas Long Beach, Ventura, Bakersfield, Calif.
Oklahoma City, Okla. Lafayette, La. Moulden Oil Field Services, Casper, Wyo. Crossville, Illinois

HOUSTON — A Leader in Petroleum Research

By C. H. Fay
Shell Oil Co. Research Laboratory

THE philosophy of industrial research is very like the philosophy of petroleum exploration, which has been summarized by the seemingly paradoxical statement that oil is discovered by drilling dry holes. It is not surprising, then, that the oil industry has become a leader in industrial research, although the aptness of the cited analogy is challenged by the historical fact that marketing problems led to refining research and development long before exploration methods began to acquire their present sophistication.

Houston, as one of the petroleum capitals of the world, is no laggard in petroleum research. Three integrated companies — Humble Oil and Refining Co., Shell Oil Co., and The Texas Co. — conduct the major part of their exploration and production research activities here. The research laboratories of Hughes Tool Co. and Reed Roller Bit Co. have contributed much to the technical progress that has made possible today's deep drilling. Progress in drilling mud technology will benefit from the improved research facilities incorporated in Baroid's new national headquarters here. Refining problems are not neglected in the area. Humble, at its nearby Baytown refinery, and Shell, at Deer Park, maintain extensive refinery research laboratories. A noteworthy feature at Baytown is the provision of higher education on the job via the Humble Lectures in

Pictured on this and the following pages are examples of research facilities of the petroleum industry in Houston. At top is a view of The Texas Co. geophysical laboratory and at left is Shell Oil Co.'s exploration and production research facilities. At upper right, next page, are multiple filter presses for testing drilling fluids at Baroid Sales Division, National Lead Co. At lower right is an architect's sketch of Humble Oil and Refining Co.'s new research building.

Science, which have enlisted the services of many distinguished university scientists.

Houston has long been a leader in geophysical instrument development. The first really successful gravity meter is generally considered to be that developed in the early thirties at Humble by O. H. Truman. One of the most highly regarded modern meters, the Worden Meter, a modified one of which was successfully used by G. P. Woollard to tie together various primary gravity base stations around the world, was developed and is manufactured in Houston. A number of seismograph contractors and instrument manufacturers operate laboratories for the development of seismic instruments and field techniques.

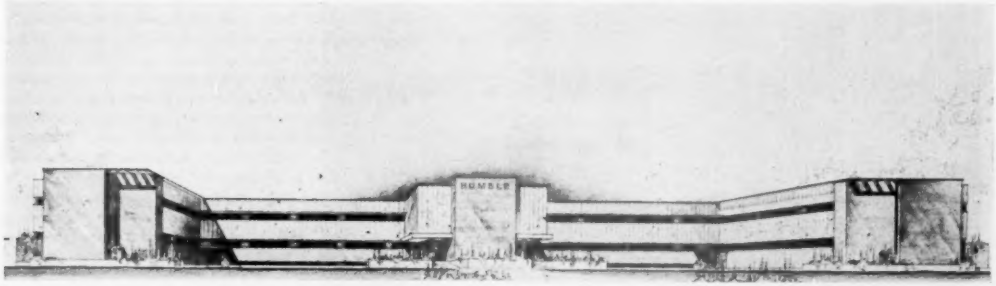
Members of the professional staffs of the larger Houston laboratories are drawn from a wide variety of fields. To classify them broadly as chemists, geologists, physicists, engineers, mathematicians, metallurgists — yes, and biologists — is to create an already imposing list, which might be made more formidable by subclassification into specialties. Some of these men are inclined by taste and temperature to delve even deeper in a narrow field, thereby becoming authorities in their chosen specialty; others, as their counterparts in the smaller laboratories must necessarily do, prefer to range over a wide variety of problems, sharpening a new set of intellectual tools as required. These groups have been described by a cynic before; the first learns more and more about less and less, the second less and less about more and more. The less cynical recognize that both groups have made significant contributions to petroleum science.

Houston research staffs have long included a number of prolific inventors. For example, a glance at the patent abstract index, 1939-47, published as part of the 1948 cumulative index of *Geophysics*, shows 30 entires for D. G. C. Hare, the result of his four years at The Texas Co. laboratories, 28 entires for L. W. Blau of Humble, and 26 for L. Horvitz, operator of an independent geochemical research laboratory.

The readers of PETROLEUM TECHNOLOGY are of course principally interest in (and, for that matter, largely already familiar with) Houston's research contributions to production engineering. The early AIME papers of Leverett, then of Humble, *et al.*, concerning capillary pressure, oil and water relative permeability, and displacement theory are still of sufficient importance to be cited with almost monotonous regularity by later contributors in these fields. The prediction of invasion patterns in cycling has been facilitated by the use of the potentiometric model developed by Alexander Wolf, then of The Texas Co., later automatized by B. D. Lee of that laboratory. The mercury injection capillary pressure technique, introduced by W. R. Purcell of Shell's Exploration and Production Research Laboratory, has proved a valuable tool for the estimation of permeabilities from measurements on cuttings. The first commercially available simultaneous gamma ray and neutron logging tool was developed by Houston's Perforating Guns Atlas Corp.

What of the future for petroleum research in Houston? Recent and current expansion in research facilities is impressive. Shell's exploration and production research plant was augmented this year by the completion of a high pressure laboratory building. A new show place among Houston laboratories is destined to be the one currently under construction for Humble. It will provide improved facilities for geological, geophysical, and production research, and also for certain routine laboratory services. Across the road from Humble's new laboratory, Magcobar will build a new headquarters which will include both research and service laboratory facilities for the advancement and application of drilling mud technology. To the extent that the future can be predicted by extrapolation, the increasing importance of Houston as a petroleum research center is certain.

This discussion would not be complete without mention of the contributions of such institutions as the Rice Institute to Houston's petroleum research community. Faculty members of Rice, both in their own research and as consultants, have contributed directly to the petroleum art. Possibly even more important are their indirect contributions. By making their library facilities available, and their colloquia open to visitors, they have provided an intellectual leaven for what might otherwise have been a stodgy loaf. ★ ★ ★



Three-Day Program Arranged For Ladies at Meeting

By Mrs. Asbury S. Parks
Chairman, Women's Activities Committee

EVERY woman loves to play hostess and I am no exception. When I was asked to help out on plans for the Fall Meeting in Houston my thought naturally turned to others who enjoy entertaining — Mary Hughes, Starr Mayfield, Maude Cashin, Lola Newsome, Gertrude Otto, to mention a few. So, it was with a great deal of pleasure that we rounded up other friends of the AIME and made plans. Now we are waiting and looking forward to returning in part the many courtesies that were extended us at previous meetings.

By "we" is meant the members of the Ladies Activities Committee — Mrs. Asbury S. Parks, Mrs. Verne Mayfield, Mrs. Jim Hughes, Mrs. D. D'Arcy Casshin, Mrs. Joe A. Newsome, Jr., Mrs. Herman Otto, Mrs. Roy Bobo, Mrs. Harold Decker, Mrs. E. P. Hayes, Mrs. Lyle Payne, Mrs. W. S. Morris, Mrs. J. W. Hood, Mrs. C. B. Truitt, Mrs. C. F. Redmon, Mrs. E. P. Hubbard, Mrs. George Nye, Mrs. J. Davis Collett, Mrs. Paul Turnbull, Mrs. Joe B. Alford and Mrs. Jess E. Adkins.

Wednesday, Oct. 1, we will have a morning Sherry in the Rice Hotel. The hour and room will be on the schedule of events. Here you will see everybody, girls from the old home town, those whom you knew in another oil field and another day, old school friends, those whose name rings a bell but whose faces are new.

We go from this party to lunch with our very best boy friends. We will have a noted speaker, one whom both men and women will enjoy. This is the first time that the ladies have been included in all of the activities of the men. We thank you, gentlemen.

Your afternoon is free. May I suggest a nap? You will probably need one before this convention is over and this is your only free time. If not a nap, here are a few ideas — art, theater, library, antiqueing, shopping. We have two art centers, the Contemporary Museum in the downtown area and the Art Museum, out Main and accessable by bus. The fall schedule of shows have not yet started but the permanent collections are well worth time spent at either or both. Unusual and beautiful murals may be seen in the following buildings: the City Hall, the Library, the Rice Hotel, the Prudential Building (this one is new and done by Peter Hurd) and the Bible Cyclorama on Shepherd Dr.

In the theater line, Houston has some of the best amateur and legitimate. The Little Theater is currently putting on musicals and being called the Houston Music Theater. The Alley Theater, The Playhouse, and for the unusual, the Melodrama Theater, Inc., have continued all summer. There are occasional matinees, and all are air conditioned. If you live in a small place and would love to browse in a good library for a few hours, the Main Library is ideally located for downtown dwellers. Most of the antique shops out North Main and Washington Ave. are of the New Orleans junk yard type. The swankier shops are in older residential sections and out Main and Fannin streets. We have many specialty shops including Mexican. Perhaps the best bargains may be found away from the busiest areas.

Wednesday night, we go to the glamorous Shamrock Hotel for a cocktail buffet around the pool. Those of you who have have not yet visited this rendezvous of the world's glamorous and otherwise will be in for a real treat. The pool is beautiful and ample, the food is tasty, the landscaping well done, the flowers fragrant and there is no escaping from that old Texas harvest moon under such settings.

Thursday morning, we go for a bus ride, a "rubber neck" if you please. We will stop for a restful Coke in Starr Mayfield's garden. We will see much of interest on a bus ride. Houston is one of the more interesting cities of the world, vigorous, and impudent in its ambitiousness. Huge, new buildings are going up everywhere, some of them quite modern in design. On even a short ride around town, literally dozens of beautifully landscaped gardens are seen. Our semi-tropical climate enables us to grow hundreds of plant materials for year round bloom. The ship channel and its colorful surroundings is a high point.

Thursday afternoon, we have a seated style show tea on the Sakowitz Sky Terrace. This is a style center of a clothes-conscious town. However, due to climate, Houston is not considered a well-dressed town. Houston serves as a testing center for prices and for hat styles. If, in the fashionable salons of the world the price of a gown is questioned, the couterier is apt to say, "Ah, but it will sell in Houston" and it does.

We have a moderate semi-tropical climate. Beginning with October, we may have rains or a blue norther, then it may be as hot as an August day. Under such varying climatic conditions it is difficult to tell you what you may need in the line of clothing. You will need a short light-weight coat, cape, stole or scarf. Furs are in order but seldom needed before November. A rain coat or an umbrella may come in handy. Perhaps your best bet would be a basic suit or dress of a sheer dark material, with fall accessories. Something that could be changed by an accessory to go to any or all of the activities. Husbands have a way of wanting to travel light. Wear comfortable shoes, since some recent statistics show that one one inch off the shoes adds ten years to the face.

Thursday night, we put on our prettiest bib and tucker and have our dinner dance at the Rice Hotel. Dress is optional. We have chosen a lovely gift as your favor: something completely feminine and something we hope that you will enjoy for many years to come. ★ ★ ★

Main St. — Houston's Shopping District

Whiteford Speaker at Opening Luncheon

William K. Whiteford, executive vice-president of the Gulf Oil Corp., will be the speaker at the Welcoming Luncheon of the 1952 Mid-Continent Fall Meeting of the Petroleum Branch, AIME, in Houston, Oct. 1. The luncheon will be held in the Ballroom of the Rice Hotel where some 1,200 petroleum engineers and their guests will gather for the three-day meeting of technical and economic sessions.

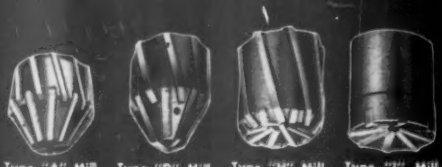
Whiteford had his first experience in the oil business in the Santa Maria oil fields of California during summer vacations while a student at Stanford University. After roustabouting and roughnecking for several years in the various California oil fields, he joined a consulting petroleum engineering firm as a field engineer in 1924. A year later, he joined the Barnsdall Oil Co. as the production engineer of the California division and was later transferred to Tulsa, Okla., as chief production engineer and superintendent of the Northern Division of the company's Mid-Continent Division.

Later, he became vice-president and general manager of all exploration and production activities for Barnsdall with the exception of the California area. In 1935, Whiteford joined the British-American Oil Co. as executive vice-president of its United States producing subsidiary at Tulsa. Eight years later, in 1942, he was elected executive vice-president of the parent company and moved to its head office in Toronto, Canada.

He was elected president of British-American the following year and chairman in 1951. He assumed his duties as executive vice-president with Gulf on Dec. 1, 1951. ★ ★ ★

KINZBACH Whipstocks and Mills-FIRST with oilmen for 24 years

Leading oil operators the world over use Kinzbach Whipstocks for side-tracking, straightening and directional drilling operations. They can be set at any depth, requiring no support for the bottom. Positive setting slips prevent slipping or turning in hole. They can be oriented to mill out in any direction. Patented hinge arrangement assures that top of Whipstock will lie close against pipe walls at all times, permitting easy passage of drilling tools. Setting trigger always locates whipstock between couplings so window will be within one joint. Available in all popular sizes of casing.



Type "A" Mill Type "D" Mill Type "H" Mill Type "I" Mill

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On Exhibit—

Equipment manufacturers and service companies will exhibit on the mezzanine of the Rice Hotel Oct. 1-3. A list of these exhibitors is given here.

ATOMIC ENERGY OF CANADA, LTD. (Booth 23) — Will introduce the Commercial Products Division of Atomic Energy of Canada, Ltd. (formerly Eldorado Mining and Refining, Ltd.) as suppliers of radioactive sources to the oil industry. Technical personnel will be in attendance to give information on both naturally occurring and pile-produced isotopes. On display will be "dummy" radium; beryllium neutron sources, polonium; beryllium neutron sources and pure gamma sources as used in oil well logging.

BAKER OIL TOOLS, INC. (Booth 8) — Will display a cut-away model of Baker Model 415-D Retainer Production Packer; cut-away models of the setting tools used to set the packer either on tubing or wire line; a cut-away model of Baker Model "K" Cement Retainer together with setting tools. Also will display a working model of Baker Model RT-8 Retrievable Cementer; a cut-away model of the Baker Cement Wash-Down Whirler Float Shoe; and a working model of the Baker Model "D" Rotary Hydraulic Wall Scraper.

B AND W, INCORPORATED (Booth 20)—Will exhibit photographs of scratchers and centralizers and field installations. A central display unit will show several scratchers in "down the hole" position. A gravel packing display will also include closely screened gravel, tools and field photographs. Equipment to be shown are Multi-Flex Scratchers, Hinged Nu-Coil and Rotating Scratchers, the Latch-On Centralizer equipped with KON-KAVE Bows.

CAMCO, INC. (Booth 24) — Will show various types of gas lift installations consisting primarily of intermittant and constant flow conditions, retrievable valves and mandrels and various cut-away sections of equipment.

CORE LABORATORIES (Booth 21) — Will serve coffee to visitors throughout the three-day meeting. Also will have a sample library, a display of 125 core samples from areas all over the United States and Canada.

THE DIA-LOG CO. (Booth 15) — Will display tubing and casing survey instruments, and plastic model tools for recovery of drill pipe, drill collars and tubing.

DOWELL INCORPORATED (Booth 3) — Will exhibit the Jel-X materials which work both mechanically and chemically in the treatment of oil and gas wells, the new Hot Wire tool used in locating zones of lost circulation, the new radio active materials used in acid and well-surveying fluids and new additives used in regular acidizing. The display will include M-38 which has shown value in aiding the return of spent acid, in increasing formation permeability and in preventing emulsions.

DRESSER INDUSTRIES, INC. (Booth 28) — Will display various activities of the several Dresser divisions with literature and personnel available for discussion.

GEORGE E. FAILING SUPPLY CO. (Booth 11) — Will exhibit products handled and have available literature describing each.

GARRETT OIL TOOLS, INC. (Booth 27) — Will have on display a complete plastic model illustrating gas lift procedure, a large display board containing cut-away models of all Garrett gas lift equipment, and numerous models of Garrett time-cycle intermitters and regulators, both pressure-reducing and back-pressure types.

GEOLOGRAPH COMPANY (Booth 6) — Will exhibit the Geolograph instrument placed on rotary drilling wells for the purpose of recording drilling time and related drilling operations. The display will also demonstrate the Geolograph method of mechanical well-logging.

HALLIBURTON OIL WELL CEMENTING CO. Will exhibit various Halliburton models of caliper tools, gun perforator, roto wall scratcher and casing centralizer. Also literature on Halliburton products and services.

HOUSTON OIL FIELD MATERIAL CO., INC. (Booth 26) — Will exhibit tools manufactured for cutting and fishing operations, directional drilling, pressure welding, sidewall coring and well surveying.

INTERNATIONAL BUSINESS MACHINES, INC. (Booths 16, 17, 18) — Will feature IBM electronic equipment in demonstrating high speed machine methods of cataloging well and reservoir data, preparing reports and computing the answers to engineering problems in the fields of production engineering and research. A representative data file containing drill stem tests, core analyses, production tests, and well histories will be used in preparing a typical operating report. Flash vaporization equilibrium calculations will be demonstrated.

JOHNSTON TESTERS, INC. (Booth 5) — Will display new developments in drill stem testing equipment. Spot lighted will be equipment for safer operation in taking a drill stem test. Scale models of equipment with slides will be shown to better illustrate the application of this new equipment.

KEYSTONE DEVELOPMENT CORP. (Booth 14) — Will exhibit the Sonolog Well Sounder, an acoustic instrument for the location of fluid level in a well casing or tubing. Alexander Wolf will be in attendance to explain the instrument.

KIMRAY, INC. (Booth 22) — Will feature full size cut-away models of non-bleed, pilot operated, low pressure gas back pressure regulators and Floatless Liquid Level Controller for separators in pressures to 4,000 psi which is also capable of controlling interface level at high pressures. Other equipment exhibited will be a single soft seated fully balanced Mechanical Oil Valve, Trunnion assemblies, fluid meters and samplers for individual well metering.

LANE-WELLS CO. (Booth 10) — Will stress recent developments that have been accomplished in perforating equipment as well as Lane-Wells radioactivity logging service. Also on display will be the Lane-Wells Hook-Wall Packer and Wire Line Drillable Bridge Plugs.

RUSKA INSTRUMENT CORP. (Booth 19) — Will display late type instruments used in the petroleum industry with literature describing each.

OTIS PRESSURE CONTROL (Booth 7) — Will include cut-away models of actual sub-surface tools and colored-up schematic illustrations of downwell pumps and packers for two-zone wells. Otis' Type A Side-Door Choke will be introduced. The latter is a new dual-completion and production tool.

SCHLUMBERGER WELL SURVEYING CORP. (Booth 4) — Will display a new logging technique and new perforating method. The logging technique — MicroLaterologging — is a shallow penetration resistivity method which permits accurate measurement of the zone in the well bore immediately behind the mud cake. Perforating equipment displayed will be small diameter expendable shaped charge carriers used in conjunction with a new permanent well completion method. Included will be a section of the gun, surface test targets, pictures of various type well setups, etc.

SHAFFER TOOL WORKS (Booth 9) — Will exhibit Shaffer hydraulically operated high-pressure drilling control equipment, the new ram type blowout preventers with self-draining ram compartments; the Shaffer rotating blowout preventer with high-pressure packing element which turns with the kelly and automatically seals around the kelly, drill pipe, tool joints and drill collars; the Shaffer-Waggener bumper safety joint and the Shaffer jar safety joint.

SOLA CATALYTIC CO. (Booth 12) — Will display a cut-away model of the tanks used in the Sola Catalytic process for treating industrial and potable water without the use of chemicals. The process has the function of retarding the formation of scale and corrosion in boilers, heat exchangers, stills, cooling water for internal combustion engines, air compressors, air conditioning systems, etc.

WELEX JET SERVICES, INC. (Booth 13) — Will display the new Four Way Jet Gun that perforates as many as 12 holes per foot, with sets of four holes on the same horizontal level.

You are cordially invited to visit
IBM's exhibit at the Fall Convention of
the Petroleum Branch of the A. I. M. E.
Demonstrations will feature versatile
IBM electronic punched card
equipment performing high speed
recording and handling of data for
production and engineering analysis.

IBM

Rice Hotel, Houston • October 1st through
October 3rd

Houston's Claim to Oil Fame

A number of cities fortunately located in the heart of great oil producing regions of the United States lay claim to being the "petroleum capitol" of the world. The fascinating business of producing and marketing oil and oil products has made many a town a city and many a city a metropolis since the turn of the century and the moving into high gear of the industrial revolution. Houston is no exception.

For Houston was caught up by the frenzied activities of the petroleum industry when both the town and oil producing techniques were in swaddling clothes. They both have matured together and prospered because of a happy combination of excellent geographical location on the part of Houston and an abundance of petroleum reserves on the part of the industry in the area.

Houston makes its claim to being the "petroleum capitol" with an imposing list of statistics among which are:

1. The Houston area is the heart of the oil industry in Texas as Texas is of the world petroleum industry.
2. The increase in production in the Houston area since 1940 was 168,000 B/D, or 10 per cent of the gain for the entire United States in the last 10 years.
3. There are 213 oil and condensate fields and over 8,400 oil wells in the 17 counties nearest Houston which have oil production.
4. The average production per well was 43 B/D, compared with 19 B/D for Texas and 12 B/D for the United States.
5. Harris County (Houston) has 36 oil fields, 1,835 oil wells, and production of 68,850 B/D in 1950.
6. The proved crude oil reserves remaining to be recovered are about 2.4 billion bbl, or about 10 per cent of United States reserves.
7. There are 21 natural gasoline and cycling plants in the area processing gas to recover liquid hydrocarbons.
8. The production of these plants is 44,500 B/D, or about 10 per cent of the United States output, recovered from over 1.5 billion cu ft of gas daily.
9. Proved gas reserves in the 19 counties of the Houston area were about 23 trillion cu ft as of Jan. 1, 1951.
10. Production of marketed gas in 1950 in the Houston area was about 2,300 MMcf/D, of which 1,040 MMcf were returned to reservoirs and 1,260 MMcf were used and marketed.
11. There are 13 refineries in the area with a crude oil processing capacity of 810,600 B/D, which is 42 per cent of Texas and 12 per cent of the United States capacity.
12. Harris County has seven refineries, including the largest in the nation and represents 73 per cent of the capacity for this area.
13. The investment in synthetic rubber facilities in the area is $134,000,000.
14. There are two butadiene, two styrene, and two copolymer plants which have a capacity to produce 112,500 tons a year of GR-S rubber.
15. There is one butyl rubber plant with a capacity of 40,000 tons.

Visit Our Booth in Houston

You are cordially invited to stop by our booth (#7) across from the registration table on the mezzanine of the Rice Hotel when you attend the Fall Meeting. We'd like to show you the new Type A Otis Side-Door Choke, especially designed for formation-fracturing, the Type H Otis Cross-Over Nipple Assembly for dually-completed wells, a new and improved Otis Tubing Caliper, details on the Otis Two-Zone Pump, and other tools and equipment. Plan to spend some time at the Otis exhibit; we'll be glad to see you.

OTIS Otis Pressure Control, Inc.

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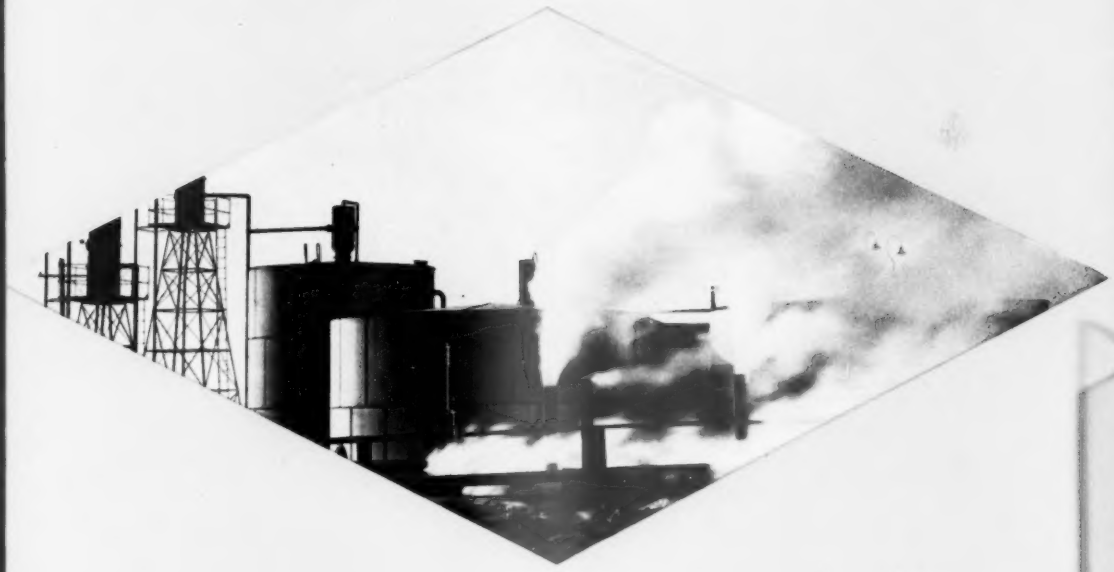

Kobe for Better Pumping

There is a steadily growing recognition of Kobe Free Pumping as the standard of top performance in pumping oil wells. This is being proved in all areas and under all conditions.

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Magcobar

IS ONE OF THE DRESSER INDUSTRIES

Magcobar's chemists and engineers are working steadily to develop new products to improve present drilling mud practices and to meet the needs of deeper drilling in the future. In this constant search, they have found new deposits of materials, developed new processes of manufacture, and have set a new standard in quality control. Wherever your rig is located . . . or whatever your drilling problem may be . . . Magcobar products and services are available to help you find a quick, effective solution.

Magnet Cove Barium Corp., *Houston, Texas.* Complete drilling mud service for the oil industry through 350 dealers at strategic locations.

Clark Bros. Co., *Olean, New York.* Engines and compressors—gas, steam and diesel driven. Slush pumps.

Dresser Manufacturing Division, *Bradford, Pa.* Pipe couplings, fittings and sleeves—rolled and welded rings—welding fittings and flanges.

Kobe, Inc., Division, *Huntington Park, Calif.* Complete hydraulic oil field pumping systems, including the Kobe Free Pump.

What is DRESSER INDUSTRIES?

Dresser Industries, Inc., is a group of companies under common ownership with a single common interest . . . to serve the oil and gas industries with a wide range of the finest equipment and supplies possible.

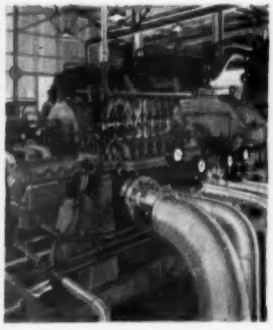
Each company is a specialist and recognized leader in its field, yet each retains its corporate identity and management. The pooled resources of engineering know-how and research facilities of the entire Dresser Industries organization back each company.

Individually or collectively, the Dresser group works in all its divisions helping to expand oil and gas facilities to meet the world's ever-increasing energy requirements. It is this planned association of companies and products that gives breadth and depth to Dresser's combined operations. This integrated line of equipment and coordinated service enables Dresser Industries to make *your* job easier and better.

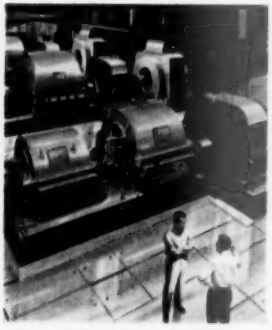
Magnet Cove Barium Corporation provides the oil industry with a complete drilling mud service. In addition to mining and processing a variety of specialized drilling mud materials, Magcobar has an expansive dealer organization, a large staff of experienced field mud engineers who travel in laboratory-equipped cars and are backed up by modern research facilities. Magcobar developed and pioneered the flotation process to beneficiate barite. This and other of the company's advanced techniques have added millions of tons of barite reserves and have saved millions of dollars for the oil industry through lower costs.

DRESSER INDUSTRIES, INC.
OIL, GAS AND CHEMICAL EQUIPMENT

ATLANTIC BUILDING ★ DALLAS, TEXAS



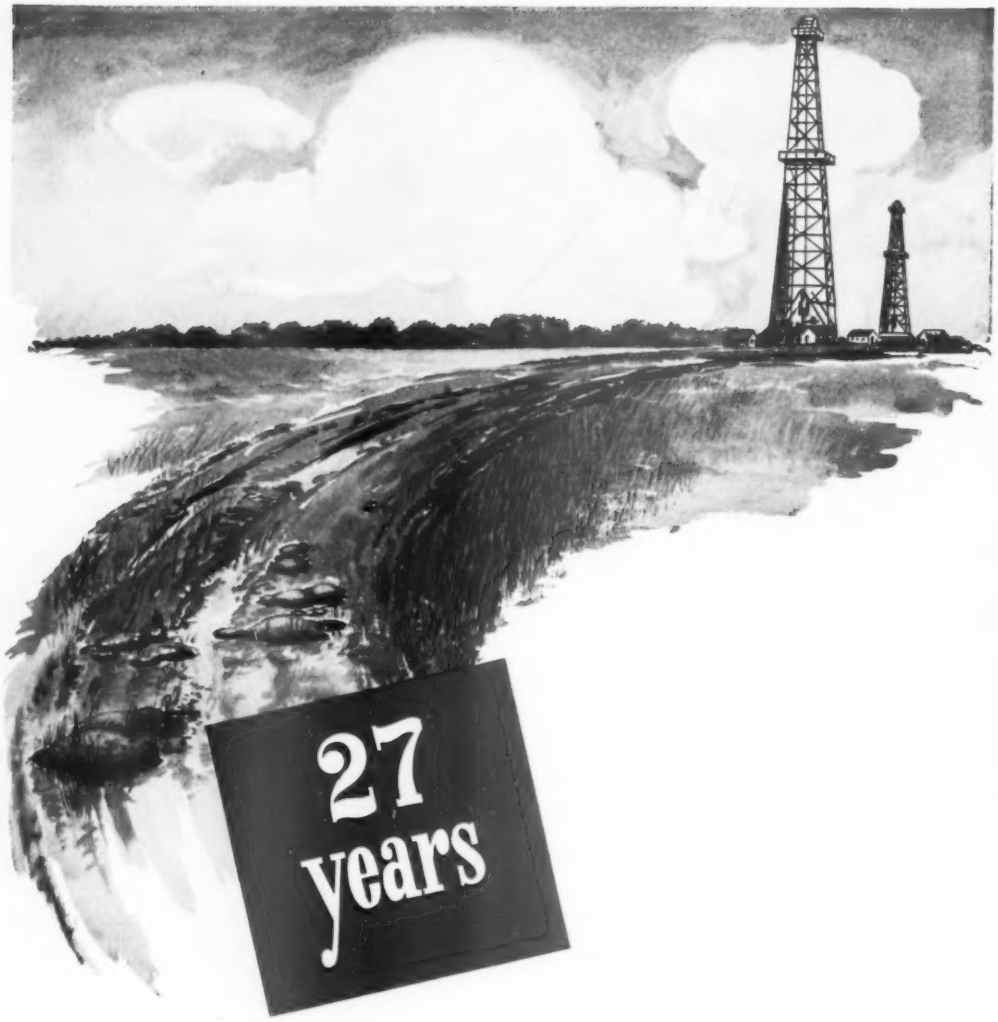
Pacific Pumps, Inc., *Huntington Park, Calif.* Centrifugal pumps, deep oil-well plunger pumps and boiler feed pumps.



Roots-Connersville Blower Division, *Connersville, Ind.* Rotary positive blowers, gas pumps; centrifugal blowers, exhausters; positive displacement meters.

Security Engineering Company, *Whittier, Calif.* Rock bits, reamers, casing scrapers, reamer rock bits, coring bits, securaloy.

Ideco Division, *Dallas, Beaumont, Tex., Torrance, Calif.* Derricks, drawworks, rambler drilling rigs, traveling blocks, rotary tables, swivels.



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GEOPHYSICAL ENGINEERING COMPANY

SAN ANTONIO, TEXAS

SEISMIC • GRAVITY • MAGNETIC SURVEYS

Post Meeting Tour Of Mexico Offered

A post meeting trip to Mexico City and surrounding points of interest is being offered members of AIME attending the Mid-Continent Fall Meeting in Houston Oct. 1-3. The tour has been arranged by the National Railways of Mexico whose general agent, F. Alatorre, may be reached at 2401 Transit Tower, San Antonio, Tex.

The eight-day planned tour will leave Houston at 7:50 a.m. Saturday, Oct. 4, via Southern Pacific Lines, arriving in San Antonio at 11:40 a.m. There the group will transfer to the Missouri Pacific depot, leaving San Antonio at 12:05 p.m. via Missouri Pacific and National Railways of Mexico. Arriving in Laredo at 4:20 p.m., the entourage will cross the international bridge over the Rio Grande and pass through Customs and Immigration inspections on board.

By Sunday morning, the train will be well into Mexico, ascending the great central mesa 5,000 ft above sea level. There will be short stops at San Luis Potosi, Queretaro and other interesting cities. The arrival in Mexico City will be at 8:00 p.m. Sunday and private automobiles will transfer the party to a modern hotel.

Throughout the week there will be tours of Mexico City's modern residential sections, Chapultepec Park and Castle, the Cathedral, the flower market and business district. There will also be glimpses into Mexico's history with visits to the Shrine of Guadalupe, the towering Pyramids of the Sun and Moon at San Juan Tectihuacan and the 16th Century monastery of Acolman. Time has been set aside for visits to the floating gardens of Xochimilco, Cuernavaca and Cortes' palace and Tasco, the old mining town clinging picturesquely to a mountainside.

On the final day of tours, Friday, a drive has been arranged over the mountains and plains to Puebla and Cholula, the latter the ancient site of the Toltec Dynasty. En route may be seen the majestic volcanoes Popocatepetl and Iztaccihuatl. At 8:20 a.m. Saturday, Oct. 11, the group will leave Mexico City, gradually descending the great plateau and arriving back in San Antonio at 1:30 p.m. Sunday, Oct. 12.

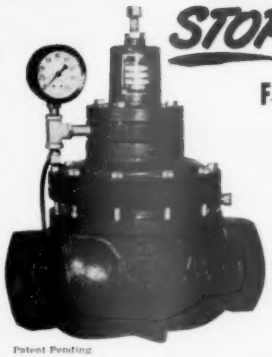
Per person costs for the tour are as follows:

Coach seat	$126.56
One in lower berth	169.36
One in upper berth	162.85
Two in lower berth	154.38
Two in compartment	181.03
Two in drawing room	196.22
Three in drawing room	177.28

These costs include 15 per cent United States tax, tourist card, transfer of passengers and luggage from and to the station in Mexico City, first class hotel in Mexico City and Tasco accommodating two persons in a room with twin beds and private bath, sightseeing trips with English-speaking guides and all meals in Mexico City and vicinity. The prices do not include meals on board the train, laundry, tips, and expenses of a personal nature. A smallpox vaccination certificate issued within the last three years is required by the United States health authorities at Laredo, Tex., point of entry into Mexico.

To apply for the tour, write F. Alatorre, general agent, National Railways of Mexico, 2401 Transit Tower, San Antonio, Tex. A deposit check in the amount of $25 made out to F. Alatorre should accompany the application. Indicate class of travel desired. ★ ★ ★

BACK PRESSURE REGULATORS



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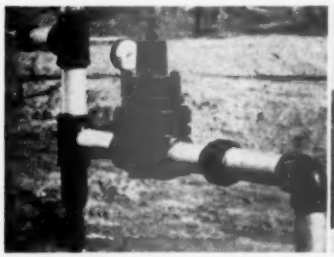
STOP GAS LEAKAGE

FROM YOUR GAS VENT LINES

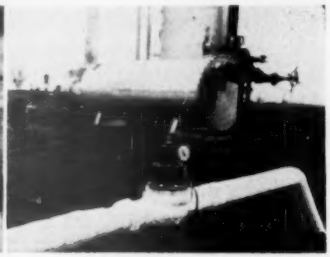
Kimray Regulators will pay dividends on gas savings. They shut off "bubble tight."

Constant pressure control unaffected by temperature changes. Full line opening—single seat non-bleed, built-in pilot.

Sizes available for immediate delivery: 2", 3", 4" screwed or flanged, 6" flanged. Contact your nearest distributor.



KIMRAY-PARKS BACK PRESSURE REGULATOR on treater vent saves gas to help fire burner.



Ice-covered KIMRAY-PARKS REGULATOR holds constant pressure despite low temperature.

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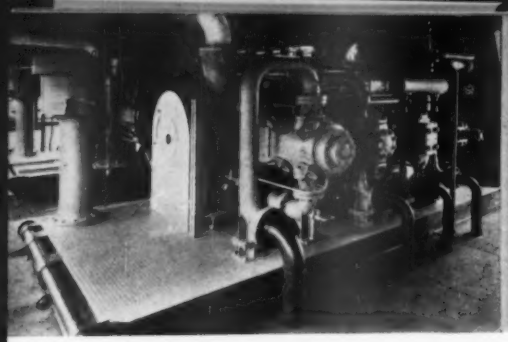
NEW IBERIA, LA.—Clif Mock Co., c/o Bill Cussry Tool Co.
DENVER, COLO.—Hinkson Oil & Gas Instrument Co.
CASPER, WYO.—Hinkson Oil & Gas Instrument Co.
OKLAHOMA CITY, OKLA.—Kimray, Inc.



Two Clark Midget Angles furnishing gas for gas lift service and to recycling plant at Cranfield, Miss.

Battery Two, Lake St. John Field, La.: Clark Midget Angle supplying gas to the Lake St. John gasoline and recycling plant.

Perfect Balance and

...explain Clark Midget Angles' success in The California Co.'s Bayou Country operations

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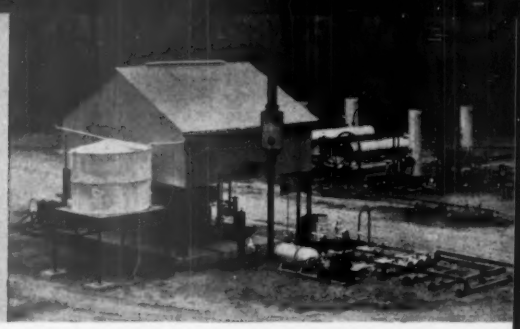
Barataria, La.: Clark Midget Angle pumping flare gas into a natural gas pipeline.

Brookhaven, Miss.: Clark Midget Angle discharging at 2500 psi into injection wells shown in background.

Battery Four in Lake St. John Field, La.: Two Clark Midget Angles furnishing gas for gas lift services and for gasoline plant at nearby Lake St. John.



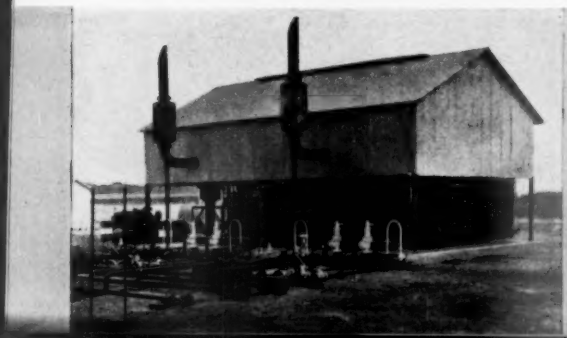
Clark Midget Angle handling 2-pressure services of field gas for Cranfield, Miss. recycling plant.

Stamina

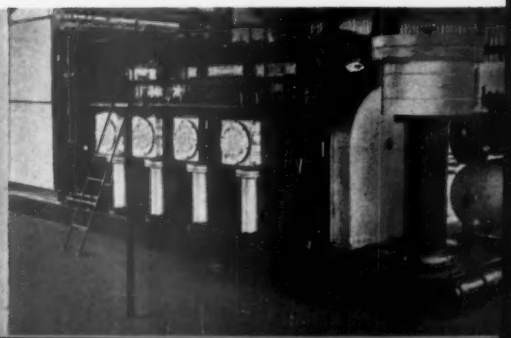
Delta Farms, in Bayous of Louisiana: Two Clark Midget Angles operating on individual floating barges. Perfect balance makes this possible.

CLARK® compressors

Two Clark Midget Angles supplying gas through 2-pressure services to nearby Lake St. John recycling plant.

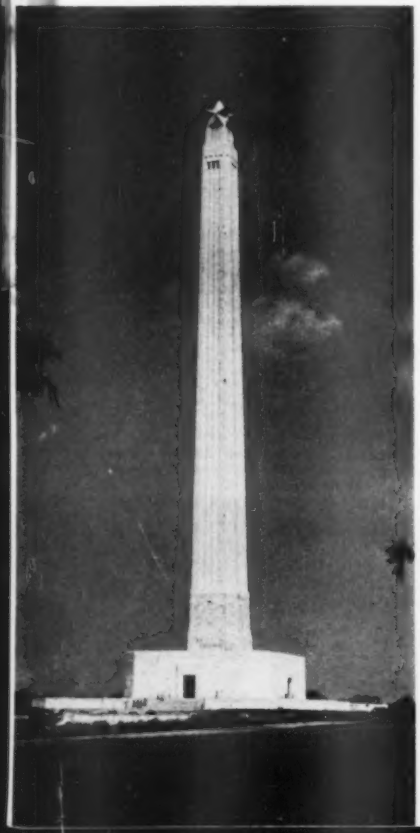


Hico Knowles, La.: Clark Midget Angle supplying gas through 2-pressure service for nearby recycling plant.



Houston Is Many Scenes

The landscape of Houston is marked with the growth of industry and the achievements of past generations. Above is a view of a portion of the 50-mile channel facilities which can load simultaneously 81 big ships. At upper right and lower left are shafts pointing skyward, the first a portable drilling rig which will soon move on, the second a monument to the city's namesake, Sam Houston. At lower right are familiar refinery scenes.



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A New Type Cooling System Integrated for All Process Plant Cooling Services, Combining the Economical Maximum Use of Air With Minimum Use of Water.

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When water in good quantity and quality is not available the COMBIN-AIRE has manifest advantages over any alternative combination of cooling equipment.

Even when ample water is available and water treatment costs are low, comprehensive comparisons will frequently indicate overall advantages of the COMBIN-AIRE system.

*** The COMBIN-AIRE unit is protected by United States patents**

COMBIN-AIRE ADVANTAGES

- **LOW WATER CONSUMPTION.** No water is used during cold weather.
- **NO TREATMENT NECESSARY** for cooling tower water.
- **NO WATER LOSS** as spray or mechanical carryover.
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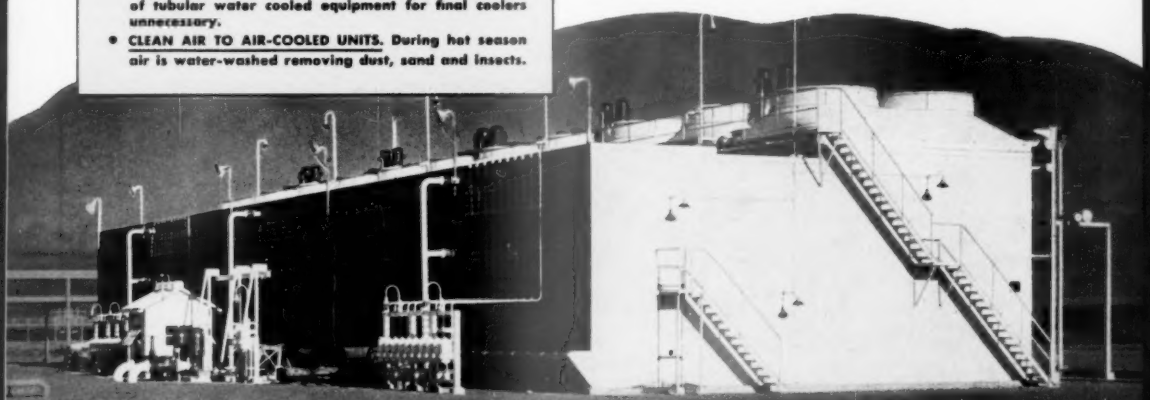
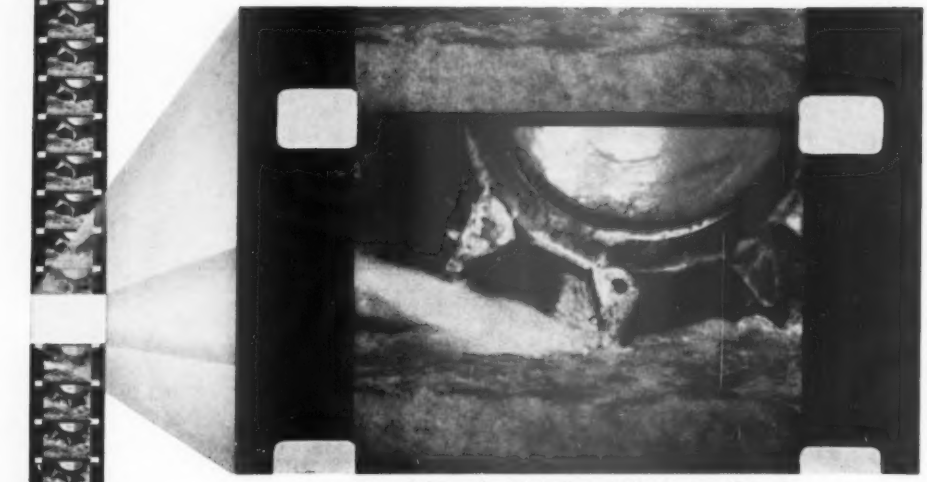


This COMBIN-AIRE unit operated by the Plymouth Oil Company in their Iowa Park plant [illegible] heat from oil absorption and fractionating plant streams, a total heat load of about 70 million B.T.U. per hour.



Unretouched frame from Hughes Research Film showing explosive effect as heel tooth penetrates formation.

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Knowing exactly what happens when bit teeth bite into the formation is essential in perfecting bit design.

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DISCUSSION OF THIS AND ALL FOLLOWING TECHNICAL PAPERS IS INVITED

Discussion in writing (3 copies) may be sent to the Editor, *Journal of Petroleum Technology*, 408 Trinity Universal Bldg., Dallas 1, Texas, and will be considered for publication in the Transactions volume *Petroleum Development and Technology*. Discussion will close December 31, 1952. Any discussion offered thereafter should be in the form of a new paper.

A METHOD FOR PREDICTING THE TENDENCY OF OIL FIELD WATERS TO DEPOSIT CALCIUM CARBONATE

HENRY A. STIFF, JR., MEMBER AIME, AND **LAWRENCE E. DAVIS**, THE ATLANTIC REFINING CO., DALLAS, TEX.

ABSTRACT

The authors previously presented a method for predicting the tendency of oil field waters to deposit calcium sulfate. The present paper gives a similar method for calcium carbonate.

Methods for predicting calcium carbonate scaling tendencies in fresh waters have been available for some time, but these could not be used for brines. By experimentally deriving the value of the *K* term in the Langelier equation, a method has been developed which applies to waters of high salt content. A statistical study is included which shows that the experimentally derived values of *K* are in good agreement with actual conditions. Several applications of the final equation to production practice are given.

INTRODUCTION

The authors previously presented a method for predicting the formation of calcium sulfate scale in oil field waters.[1] Although calcium sulfate deposition is important in production operations, the majority of scale problems involve calcium carbonate. The present communication discusses a method by which the formation of this type of scale in oil field waters can be predicted.

Calcium carbonate precipitation is caused by a shift toward carbonate in the carbonate-bicarbonate-carbon dioxide equilibrium. When equilibrium shifts in the other direction, the precipitate goes back into solution. Since there is usually considerable delay between the establishment of an equilibrium and the precipitation or solution of calcium carbonate, unstable conditions exist in which a water will precipitate or dissolve calcium carbonate on standing.

Tillmans,[2] who did a major part of the early work on carbonate scaling, pointed out that the condition of equilibrium not only indicates the tendency of a water to scale but also is an indication of its corrosive properties. Previously precipitated calcium carbonate combines with iron to form a dense crust which inhibits corrosion. If the water tends to dissolve carbonate, the scale becomes porous, and electrolytic corrosion takes place. Tillmans' work was extended by several investigators until in 1934 Langelier[3] developed an equation setting forth the conditions of carbonate equilibrium. By the use of this equation the *pH* of a water at equilibrium can be calculated. If the actual *pH* is higher than the calculated *pH*, the water has a tendency to form scale. If it is lower, the water has a tendency to be corrosive.

Langelier's equation can be expressed in a simple form as follows:

$$SI = pH - pCa - pAlk - K$$

where:

SI is the stability index. A positive index indicates scale formation. A negative index indicates corrosion.

pH is the *pH* of the water sample, as actually determined.

pCa is the negative logarithm of the calcium concentration.

pAlk is the negative logarithm of the total alkalinity.

K is a constant, the value of which depends on the total salt concentration and the temperature.

This equation has been shown to apply to waters with total solid concentrations as high as 4,000 ppm. In fact, control of fresh water treatment by means of this equation has been standard text-book practice for a number of years. Nomographs have been worked out[4] so that the stability index of a fresh water sample can be determined in a matter of minutes. Most oil field waters, however, contain well over 4,000 ppm of salts and for this reason the usual application of Langelier's equation can not be made.

By an empirical method we have extended the application of the Langelier equation to waters of high salt concentration. By the use of this equation the tendency of oil field waters to deposit calcium carbonate can be predicted.

THEORETICAL

When a water is in equilibrium the stability index is zero. The Langelier equation then becomes:

$$0 = pH - pCa - pAlk - K$$

and,

$$K = pH - pCa - pAlk$$

[1] References given at end of paper.

Manuscript received in the Petroleum Branch office March 18, 1952. Paper presented at the Houston meeting Oct. 1-3, 1952.

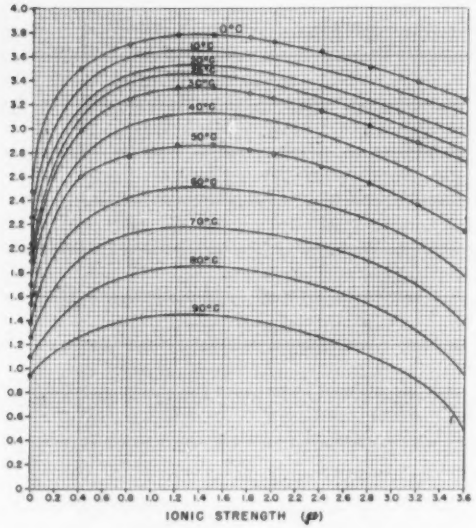

FIG. 1 — VALUES OF K AT VARIOUS IONIC STRENGTHS.

The value of K depends on the temperature and total salt concentration of the water. If a water is allowed to come to equilibrium with calcium carbonate the value of K for that particular water can be found by determining the pH, calcium and alkalinity, and substituting in the above equation. By making such determinations on waters of varying salt content in equilibrium at different temperatures, data can be obtained from which values of K at any salt content or temperature can be taken.

Different salts influence the value of K to different extents. In fresh waters this effect is negligible, but in salt water it must be taken into account. Corrections are obtained by substituting ionic strength for total salt concentration by the usual methods. Ionic strength can be calculated as follows:[5]

$$\mu = .5\ (C_1V_1^2 + C_2V_2^2 - - + CnVn^2)$$

where:

C is the concentration of each ion expressed as gram ions per 1,000 gms of solvent.

V is the valence of that ion.

EXPERIMENTAL

To various concentrations of sodium chloride ranging from 0 per cent to 20 per cent were added solutions of calcium chloride and sodium carbonate of such strength that calcium carbonate would precipitate out and leave an excess of calcium chloride. A few drops of hydrochloric acid were added to form bicarbonate and the solutions brought to equilibrium by shaking at constant temperature for 24 hours. The solutions were then filtered and the concentration of carbonate, bicarbonate, chloride, and calcium determined by actual analysis. Temperatures employed were 0°, 30°, and 50°C.

Analytical determinations insofar as possible were carried out at the equilibrium temperature. Standard procedures of analysis were used. All titrations, with the exception of chloride, were performed on the Beckman Automatic Titrator.

RESULTS

Fig. 1 shows curves giving the values of K at various ionic strengths. Curves at 0°, 30°, and 50°C were plotted from experimental data, while the curves at all other temperatures were extrapolated.

The stability indices of 100 salt water samples taken at random from our files were calculated. The frequency distribution curve is shown in Fig. 2. It will be noted that the curve is of typical shape and that the maximum frequency is at a point where the stability index is close to zero. Since it is probable that the stability indices of brines, as well as those of fresh waters have normal distribution, we believe that Fig. 2 indicates that the values of K are probably valid.

APPLICATION

To facilitate calculation of the stability indices of various oil field waters, we have included in the report Table I, which gives the factors used to obtain the ionic strength from the results of a standard water analysis. The individual ion is simply multiplied by the appropriate factor. The sum of these products gives the ionic strength.

Also included is a graph (Fig. 3), from Langelier, by which the values of $pAlk$ and pCa can be obtained.

From the ionic strength, calculated as above, the value of K can be taken from Fig. 1.

The values of these terms when substituted in the following equation will give the stability index.

$$SI = pH - K - pCa - pAlk$$

Stability index calculation on oil field brines can furnish valuable information in petroleum production operations where

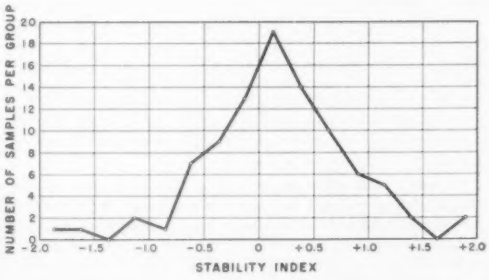

FIG. 2 — DISTRIBUTION CURVE — STABILITY INDEX OF 100 WATER SAMPLES COLLECTED AT RANDOM.

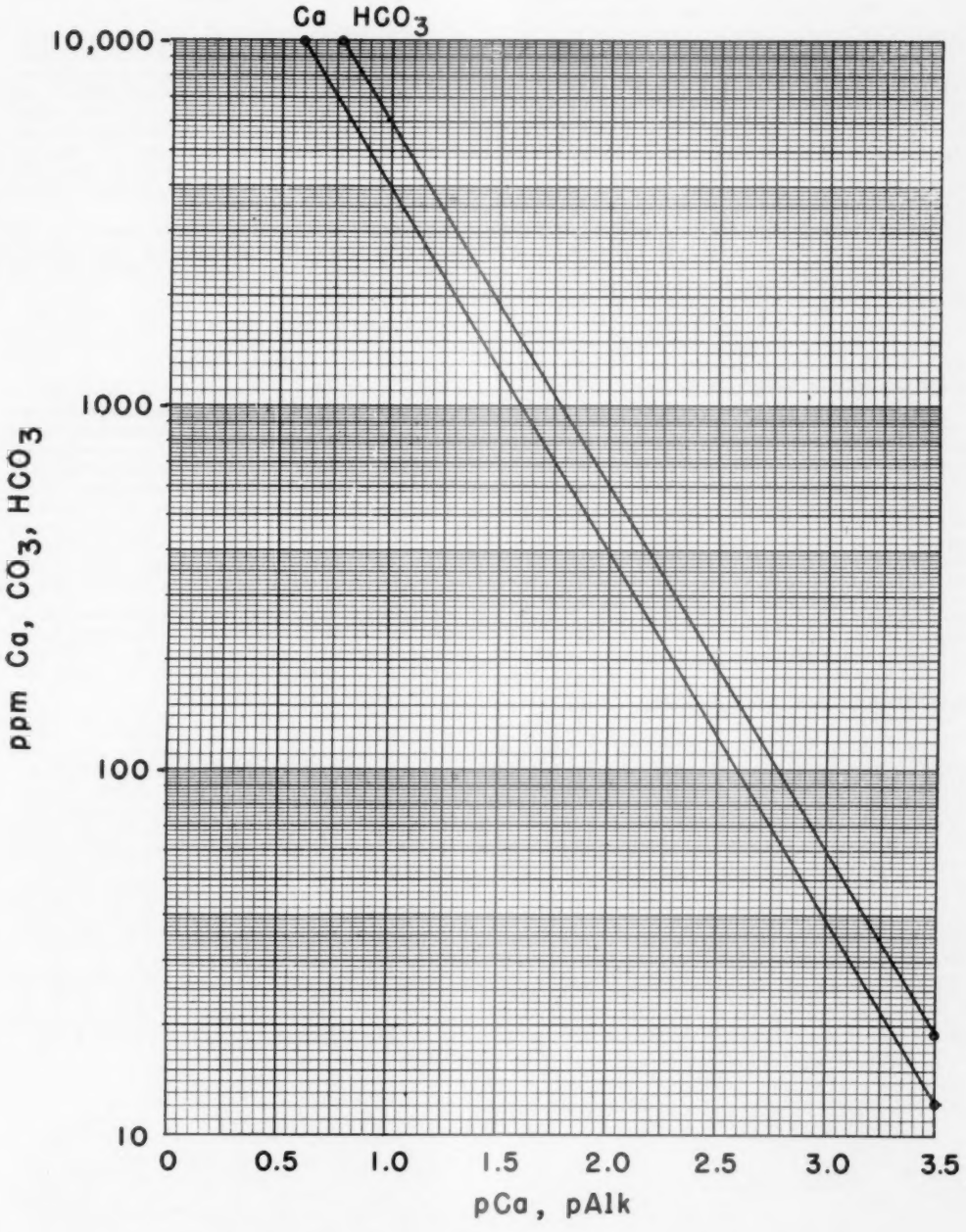

FIG. 3 — GRAPH FOR CONVERTING PARTS PER MILLION OF CALCIUM AND ALKALINITY INTO *pCa* AND *pAlk*.

Table I — Factors for Converting the Results of a Water Analysis to Ionic Strength

(The total ionic strength is the sum of the ionic strengths of the individual ions)

Ion	Factor, ppm	Factor, meq/liter
Na	2.2×10^{-5}	5×10^{-4}
Ca	5.0×10^{-5}	1×10^{-3}
Mg	8.2×10^{-5}	1×10^{-3}
Cl	1.4×10^{-5}	5×10^{-4}
HCO_3	$.8 \times 10^{-5}$	5×10^{-4}
SO_4	2.1×10^{-5}	1×10^{-3}

carbonate scaling and certain types of corrosion are involved. Following are a few examples of the application of the stability index.

Scale Deposits in Heater Treaters

A consideration of Fig. 1 shows that the value of K diminishes as the temperature of the water increases. This results in a more positive index which in turn indicates an increase in scaling tendencies. Thus, a brine which is stable at the wellhead is often scale forming at the higher temperature of the heater. The calculation of stability index for the first time makes possible the quantitative calculations of scaling tendencies of oil field waters under these conditions. It is believed that the judicious use of this tool in study of scaling condition in heater treaters will not only clarify the mechanism of these problems but also will be of considerable aid in prescribing treatment.

Scale Deposits in Producing Wells

Calcium carbonate deposits in producing oil wells is a serious problem because of loss of production and possible damage to in-hole equipment. Fundamentally, such deposits appear to be due to pressure drops which allow the escape of carbon dioxide. The resulting shift in equilibrium causes the calcium carbonate to precipitate. Usually equilibrium is not completely reached so that wellhead water samples often give an indication of the tendency for scale to form in the well.

It should be pointed out, however, that while the stability index foretells the future behavior of a water, it does not necessarily indicate its past. Actually there may be several equilibrium states in the water between the formation and the wellhead, a condition which could lead to corrosion at one point and scale at another. Studies are now in progress which we hope will clarify this situation and considerably extend the application of the stability index to the problems of scaling and corrosion in producing wells.

Water Flood and Water Disposal

The importance of injecting stable water into the formation has long been recognized, and a considerable amount of money has been spent in achieving this end. If water with a tendency to scale is injected, calcium carbonate deposits soon plug the formation. In the case of a fresh water flood the standard Langelier formulas can be used to control treatment and make sure that a stable water is being injected, but when salt water is used these equations do not apply. In such water flood operations the new stability index has found extensive application.

Disposal projects almost always involve water of high salt content. Here the injection of stable water is just as necessary as in water flooding. In this project the new stability index has proved valuable.

CONCLUSIONS

Experimental values were developed for the K term in the Langelier equation. By the use of these values the stability index of oil field waters can be calculated. A statistical evaluation of these values was made and several applications of the stability index to production problems are given.

ACKNOWLEDGMENT

The authors wish to thank The Atlantic Refining Co. for permission to publish this paper, and to acknowledge the valuable assistance and cooperation of the staff of the Chemical Engineering Group of this organization. Illustrations were prepared by Gene Nigh.

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T.P. 3397

ELECTRICAL RESISTIVITY MEASUREMENTS ON RESERVOIR ROCK SAMPLES BY THE TWO-ELECTRODE AND FOUR-ELECTRODE METHODS

C. F. RUST, MAGNOLIA PETROLEUM CO., DALLAS, TEX.

ABSTRACT

Experimental evidence is presented showing that reproducible formation resistivity factor measurements and resistivity index determinations on reservoir core samples may be made utilizing either the two- or four-electrode methods. Equipment is described which permits the application of either technique to the core specimen without loss of time and with a minimum amount of effort. Since electrical resistivity measurements on reservoir rocks are important not only in electric log interpretations, but also in the study of fundamental rock parameters, it was considered desirable to compare the applicability of both techniques of resistivity measurement.

INTRODUCTION

The techniques employed in the measurement of electrical resistivity on reservoir rocks, as practiced in the petroleum industry, may be reduced to two fundamental methods: one utilizing two electrodes only, usually referred to as the two-electrode method; the other using two additional electrodes and commonly known as the four-electrode method. In the former, the core sample whose resistivity is to be measured is mounted between two electrodes, usually metal discs, which serve to pass a current of known magnitude through the sample. The potential drop across the sample, measured between these same two electrodes, and the core dimensions furnish the necessary data to compute the resistivity of the sample. In the four-electrode technique the end plates, again usually of metal, still serve as current electrodes. Additional probes or electrodes dispersed along the sample are utilized to measure the potential drop. Both methods are used in practice[1,2] and it is the purpose of this paper to compare the two techniques as applied to the determination of formation resistivity factors and the resistivity index exponent n, in Archie's[3] empirical equation $I = \rho/\rho_o = S_w^{-n}$. To evaluate the two techniques it is desirable to point out the experimental precautions which must be taken to insure reliable results. It is evident from the electrode arrangements of the two- and the four-electrode methods that, for a given sample, the volume of sample included by the four-electrode method is less than the volume included by the two-electrode method.

One of the prime difficulties associated with the two-electrode method is the possible occurrence of an abnormally high resistance between the electrodes and the brine-saturated sample, which results in erroneous resistivity values for the core sample itself. Attempts to alleviate this difficulty meet varying degrees of success. Methods used in the past employ such absorbent materials as brine-saturated Kleenex, chamois, or felt. A technique described by Morgan, Wyllie, and Fulton,[2] appears to be more satisfactory. Their method consists of spraying or painting the end areas of a core sample with conductive silver paint. This technique reduces contact resistances between the porous medium and the electrodes to a value which is generally negligible as compared to the resistance of the sample itself.

In the four-electrode method these requirements are not as stringent since separate probes are used to measure the potential difference across a portion of the sample. In this case, contact resistance occurring at the current electrodes are of no consequence, and those appearing at the potential

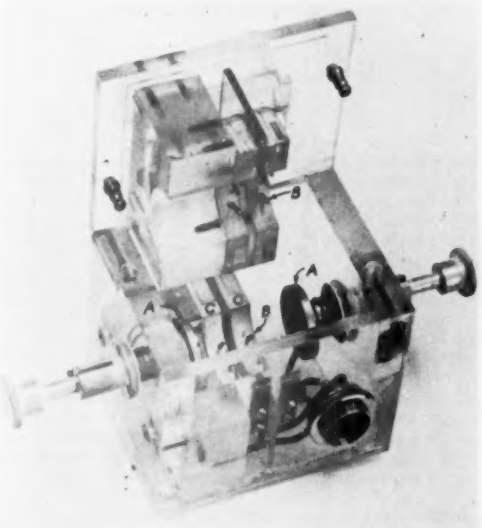

FIG. 1 — CORE SAMPLE RESISTIVITY CELL.

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office June 20, 1952.
Paper presented at Houston meeting, Oct. 1-3, 1952.

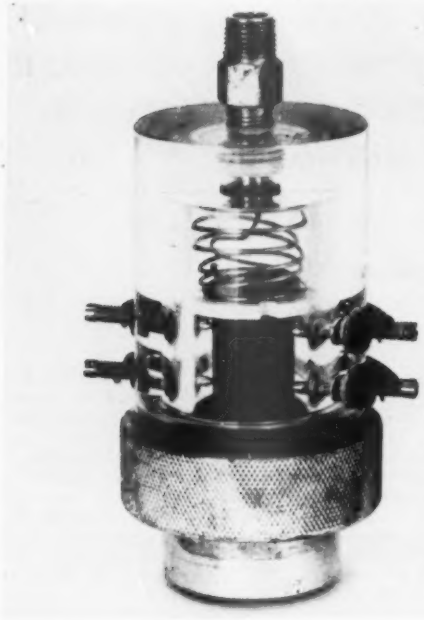

FIG. 2 — COMBINED INTERSTITIAL WATER AND RESISTIVITY CELL.

probes are easily detected by a method to be described below. However, for the measurements presented in this paper, techniques were used which reduced contact resistances at the current and potential electrodes to a minimum.

EQUIPMENT

The resistivity cell developed by Magnolia Petroleum Co.'s Field Research Laboratories and used for the determination of formation resistivity factors presented in this report is shown in Fig. 1. It is designed to permit either a two- or four-electrode measurement to be made without disturbing the core sample once it is placed in the cell. The electrode system is enclosed in a Lucite housing which is partially filled with brine to reduce evaporation of water from the core sample during the measurement. The metal disc current electrodes are seated in a ball-and-socket joint. Two sets of six solid-silver potential probes *B*, also under spring tension, are distributed along the core circumference and seated in each of two electrically insulated metal blocks *C*. The electrical wiring of the cell is permanent, and connections to the measuring circuit are made through a Cannon plug. The end areas of the core samples measured in this cell may be coated with conducting silver paint,* if the cell is used for two electrode measurements. For four-electrode measurements refined techniques, to eliminate contact resistances between the current electrodes and the core sample, are not necessary, since they do not affect the resistance measurements of the sample. This resistivity cell accommodates samples having a maximum diameter of 1 in.; the limiting lengths are between 0.75 and 1.5 in.

A combined interstitial water and resistivity cell is used for electrical resistivity determinations during the process of capillary desaturation. It is shown in Fig. 2. In this technique, the brine-saturated core sample is placed in contact with a porous diaphragm, permeable to brine but impermeable to isooctane, the medium used to displace the brine. Pressure is applied in steps to the displacing medium, forcing the brine through the diaphragm into a graduated pipette, which permits the amount of expelled brine and thus the sample brine saturation to be determined volumetrically. Resistivity measurements are made, using an electrode system similar to the one described above, except that the brine-saturated porous diaphragm replaces one of the metal disc current electrodes. The cell is mounted in a constant-temperature box to minimize effects of temperature fluctuations during the process of measurement.

PROCEDURE

A schematic wiring diagram of the electrical measuring circuit, used in conjunction with either resistivity cell, is shown in Fig. 3. With the core sample mounted in the cell, the desired current through the sample is obtained by adjustment of the potential drop across a 100-ohm wire-wound precision resistor. Manipulation of selector switches I and II permits potential-drop measurements to be made, either across the entire core sample (two-electrode method), or across a portion of the sample (four-electrode method). Any appreciable contact resistance introduced in the measurement is detected by inserting a resistor in series with the vacuum tube voltmeter. The value of this resistor is chosen to be equal to the input impedance of the measuring instrument. If the contact resistance is zero, the potential drop across the sample is one-half of that measured without the resistor in the circuit. This is a well-established procedure in electrical measurements and was first reported in petroleum literature by Dunlap *et al.*[1] With this circuit it is possible to make reliable resistivity measurements in rapid succession, using either the two- or four-electrode methods.

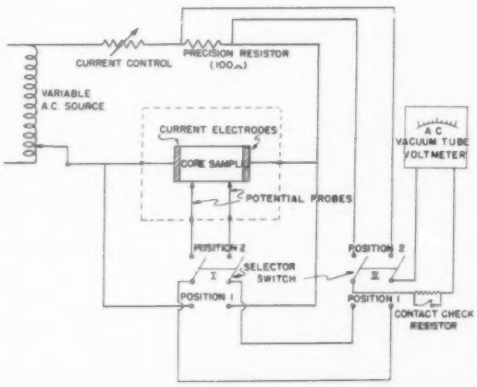

FIG. 3 — CIRCUIT DIAGRAM FOR RESISTIVITY MEASUREMENTS ON POROUS ROCKS.

*Type S.C. 11 Microcircuits Co., New Buffalo, Mich.

Table I — Two- and Four-Electrode Resistivity Measurements on Saturated Core Samples

Sample Number	Formation	Effective Porosity %	Nitrogen Permeability md	Resistivity, Ohm-Meters		Per Cent Brine Saturation	Salinity of Saturating Brine ppm NaCl
				Two-Electrode Method	Four-Electrode Method		
3158	Aux Vases SS	25.6	307	1.66	1.42	98.1	50,000
3159A	Aux Vases SS	21.6	80.8	6.86	6.76	100	10,000
3161	Aux Vases SS	21.7	122	2.04	1.81	99.2	50,000
3162	Aux Vases SS	20.7	56.8	7.31	7.45	95.7	10,000
3163	Aux Vases SS	23.3	129	6.46	6.16	99.1	10,000
3166	Aux Vases SS	23.2	170	6.46	6.60	98.0	10,000
3158	Aux Vases SS	25.6	307	0.86	0.82	98.0	100,000
3161	Aux Vases SS	21.7	122	1.10	1.04	99.0	100,000
3159	Aux Vases SS	21.0	80.0	7.52	7.39	100	10,000
3162*	Aux Vases SS	20.7	56.8	7.13	7.24	100	10,000
3163	Aux Vases SS	23.3	129	1.99	1.83	95.2	50,000
3166	Aux Vases SS	23.2	170	1.87	1.68	96.1	50,000
A-4	Stevens SS*	20.2	24.1	0.26	0.25	99.7	50,000
E-1	Stevens SS*	19.0	43.6	8.29	8.47	99.6	1,000
E-2	Stevens SS*	19.3	39.7	5.08	5.12	99.2	20,000
1459	Edwards LS	38.2	82.5	1.88	1.89	91.4	50,000
K-1	Alundum	20.0	818	5.25	5.10	98.0	10,000
2220	Annona Chalk	23.9	0.5	2.15	2.10	93.0	50,000
2221	Annona Chalk	33.0	1.4	1.35	1.36	93.2	50,000
2222	Annona Chalk	31.0	1.7	1.33	1.20	94.7	50,000
2223	Annona Chalk	27.7	1.7	1.60	1.52	95.0	50,000
2228	Annona Chalk	25.0	1.4	2.00	2.25	93.0	50,000
2231	Annona Chalk	29.3	0.9	1.64	1.61	96.0	50,000
2233	Annona Chalk	28.9	1.0	1.51	1.56	95.4	50,000
2235	Annona Chalk	28.5	1.1	1.62	1.72	95.7	50,000
2244	Annona Chalk	24.4	0.8	1.99	2.10	96.0	50,000
2248	Annona Chalk	23.1	0.9	2.08	2.24	97.2	50,000
2251	Annona Chalk	31.5	1.1	1.47	1.57	96.8	50,000
1890	Bearhead SS*	24.4	278	0.60	0.50	98.0	50,000
2809	Cotton Valley SS*	10.0	0.5	5.06	5.30	95.0	100,000
2819	Cotton Valley SS*	9.9	0.4	4.72	4.77	93.8	100,000
2822	Cotton Valley SS*	7.3	0.6	4.99	5.00	96.0	100,000
2826	Cotton Valley SS*	8.4	0.5	8.65	8.70	96.2	100,000
2827	Cotton Valley SS*	11.2	0.4	3.88	4.21	96.4	100,000
3164	Aux Vases SS*	22.3	121	53.0	55.5	98.0	500
3161	Aux Vases SS*	21.7	122	27.1	28.8	99.0	1,000
3164	Aux Vases SS*	22.3	121	26.5	27.8	100	1,000
3158	Aux Vases SS*	25.6	307	24.5	25.1	99.7	1,000
3919A	Stevens SS	20.0	92.5	20.6	20.1	98.4	1,000
3519C	Stevens SS	19.4	52.0	20.0	18.9	99.0	1,000
3519H	Stevens SS	19.5	85.3	24.5	23.7	98.2	1,000
3519J	Stevens SS	18.7	67.0	21.2	19.1	99.5	1,000
3519K	Stevens SS	18.7	71.0	22.1	20.9	99.8	1,000
3519L	Stevens SS	19.1	75.8	22.7	22.6	99.7	1,000
4021C	Madison LS	9.5	0.1	9.19	9.44	97.9	75,000
4022I	Madison LS	5.5	0.1	16.9	16.7	95.5	75,000
4023C	Madison LS	5.3	0.1	27.5	29.8	96.8	75,000
4023S	Madison LS	5.2	0.1	23.0	22.6	97.4	75,000
4024B	Madison LS	7.5	0.1	14.1	14.8	94.7	75,000
4024F	Madison LS	6.7	0.1	13.8	13.4	94.1	75,000
4024L	Madison LS	7.8	0.1	13.7	14.0	94.2	75,000
4025B	Madison LS	9.4	0.1	12.0	11.0	95.8	75,000
4025C	Madison LS	11.1	22.0	6.58	6.78	92.9	75,000
4025D	Madison LS	10.9	24.5	6.92	6.98	98.3	75,000
4025H	Madison LS	10.2	0.6	7.44	6.98	100	75,000
4026E	Madison LS	12.2	0.1	6.02	5.16	93.7	75,000
4027E	Madison LS	6.6	0.1	9.93	9.88	95.2	75,000
4027H	Madison LS	5.2	0.1	13.1	12.7	99.4	75,000
4025D	Madison LS	10.9	24.5	32.8	32.8	98.0	7,000
4025I	Madison LS	10.4	4.5	32.7	31.3	99.1	1,000

*Painted Core Samples

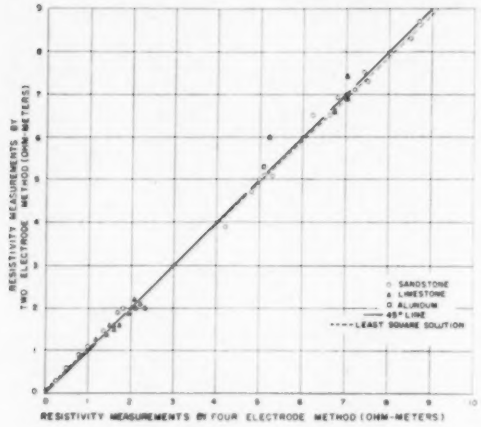

FIG. 4 — RESISTIVITY MEASUREMENTS. TWO- VS FOUR-ELECTRODE TECHNIQUES. RANGE 1-10 OHM METERS.

DISCUSSION

The electrical resistivities of 60 core samples were measured utilizing both the two-electrode and four-electrode systems. These samples, nominally three-fourths in. in diameter and one in. in length, were selected from typical sandstone and limestone formations. The brine saturations were determined in the following manner: the core samples were cleaned, dried in an oven, and weighed. The pore volumes were then measured with a Kobe gas-compression porosimeter.[4] Following this measurement, the samples were placed in a bell jar, evacuated, and flushed several times with carbon dioxide. The brine was then admitted to the evacuated chamber and the weight of the saturated samples subsequently was determined. From these data the degree of saturation was computed as a fraction of the measured pore volume. The range of saturations so obtained varied between 91.4 and 100 per cent.

Resistivity measurements were made on the above samples using both techniques. The results of these determinations are summarized in Table I and plotted in Figs. 4 and 5. Fig. 4 covers the resistivity range from 0 to approximately 10 ohm-meters; Fig. 5 includes the results ranging from 6 to 36 ohm-meters. It is evident that the data points fall closely on a line whose slope is unity. A least-square solution[5] of the data for the resistivity range from 0 to 10 ohm-meters (Fig. 4) shows that the equation of the line of best fit is of the form $y = ax + b$, in which a is the slope of the line, and b the intercept with the y-axis. The values of these constants are $a = 0.988$ and $b = 0.039$. For the data in Fig. 5, covering a range from 6 to 36 ohm-meters, $a = 0.952$ and $b = 0.978$. The dotted lines represent the lines of best fit, obtained by the method of least squares.

The agreement between the two methods depends among other things on the nature of the sample. For homogeneous samples the agreement is invariably excellent, as would be anticipated for situations in which the contact resistance is negligible. On the other hand, for heterogeneous samples, small deviations, such as are observed in these data, are inevitably observed. A practical illustration of the agreement of resistivity measurements made with both techniques on samples from a single formation, the Annona Chalk, is shown in Fig. 6. Formation resistivity factors, representing the ratio of the resistivity of a sample to the resistivity of the saturating brine, are plotted *vs* the porosity fractions on log-log paper. The open circles represent data points obtained from resistivity measurements with the four-electrode technique, and the solid circles represent the data obtained from the two-electrode measurements. This type of plot is commonly used to determine the "cementation factor," m, in Archie's[2] relation $F = \phi^{-m}$; it shows that the scattering is somewhat larger for the two-electrode data. However, the effect on the determination of the cementation factor m is small.

Measurements on core samples during the process of desaturation are complicated by the fact that not only is the resistivity measurement itself involved, but reliable determinations of the volume of expelled brine, and hence of the brine saturation of the sample, are required. For these measurements the combined interstitial water and resistivity cell, shown in Fig. 2, is used. This cell permits the obtention of data for the capillary pressure curve as well as the necessary information for Archie's[2] empirical saturation equation $I = \rho/\rho_o = S_w^{-n}$. In these capillary pressure experiments as the pressure is increased the saturation decreases and in time, becomes substantially constant at a given capillary pressure. This constant value of saturation is the equilibrium saturation obtained at the applied capillary pressure. In a like manner the resistivities change continuously as the saturation decreases in a capillary pressure experiment and therefore the resistivities may be plotted against both equilibrium and non-equilibrium saturations.

Fig. 7 is a plot of the resistivity index *vs* brine saturation for a "clean" sandstone core sample from the Planulina sand of the miocene. The designation "clean" implies that the

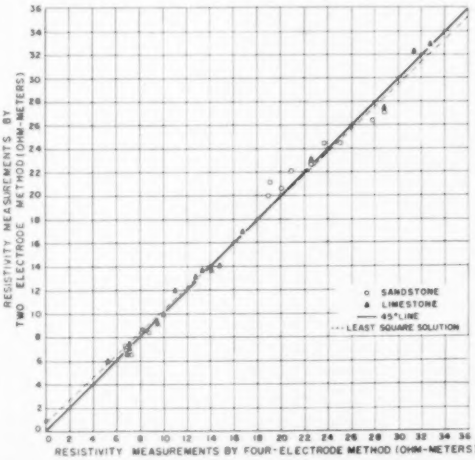

FIG. 5 — RESISTIVITY MEASUREMENTS. TWO- VS FOUR-ELECTRODE TECHNIQUES. RANGE 6-36 OHM METERS.

Table II — Resistivity Index as a Function of Brine Saturation, Planulina Sand of Miocene
Permeability 112 md
Effective Porosity 19.3%

Run 1 Two-Electrode Method			Run 1 Four-Electrode Method			Run 2 Four-Electrode Method		
Capillary Pressure psi	Brine Saturation Per Cent of Pore Volume	Resistivity Index $I = \rho/\rho_o$	Capillary Pressure psi	Brine Saturation Per Cent of Pore Volume	Resistivity Index $I = \rho/\rho_o$	Capillary Pressure psi	Brine Saturation Per Cent of Pore Volume	Resistivity Index $I = \rho/\rho_o$
0	100	1.00	0	100	1.00	0	100	1.00
0	96.4	1.10	0	96.4	1.04	4*	35.2	6.21
2	45.0	3.84	2	45.0	4.13	8*	29.4	8.46
2*	43.1	4.45	2*	43.1	4.32	12*	26.2	9.51
4	37.7	5.60	4	37.7	5.39	20*	21.5	13.3
4*	36.5	5.71	4*	36.5	5.87			
8	32.5	7.00	8	32.8	6.48			
8	31.8	7.18	8	31.8	7.32			
8*	30.6	8.10	8*	30.6	7.67			
12*	27.4	9.71	12*	27.4	9.41			
16*	26.2	10.4	16*	26.2	10.1			
20*	22.2	14.0	20*	22.2	12.6			

*Equilibrium saturation values

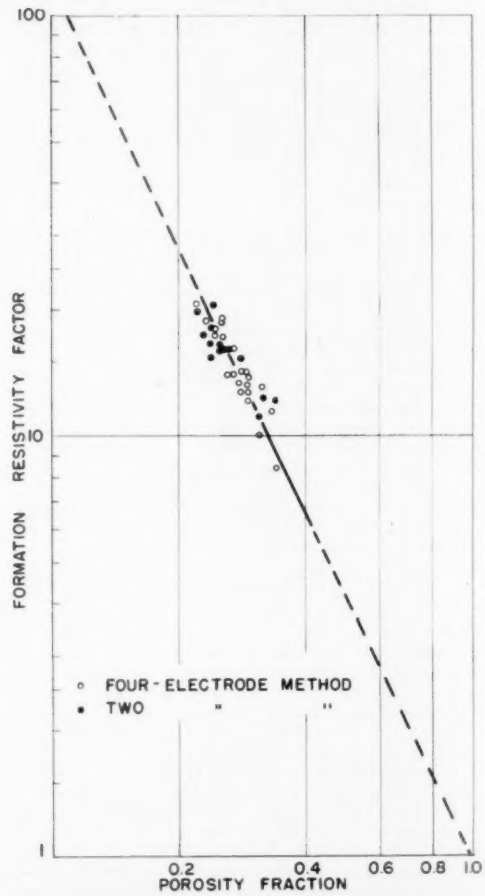

FIG. 6 — FORMATION RESISTIVITY FACTOR VS POROSITY FRACTION. ANNONA CHALK FORMATION.

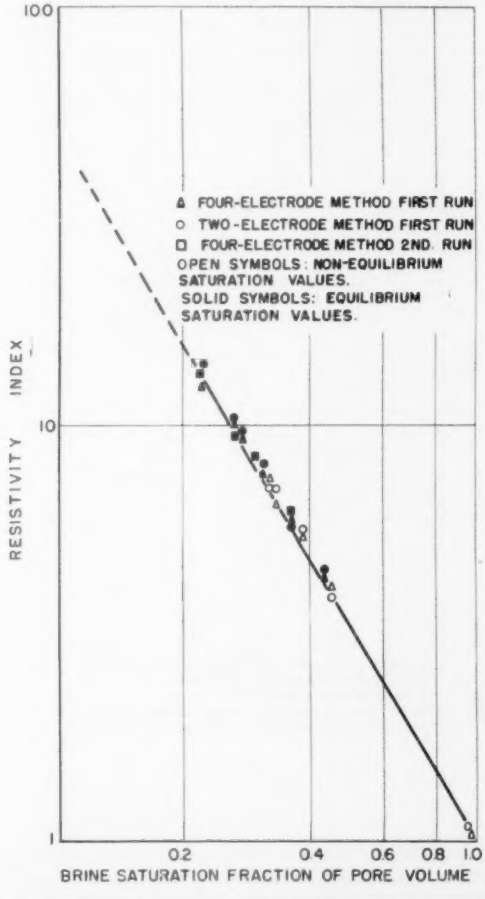

FIG. 7 — RESISTIVITY INDEX VS BRINE SATURATION. PLANULINA SAND. GAS PERMEABILITY 112 md. EFFECTIVE POROSITY 19.3%.

Table III — Resistivity Index as a Function of Brine Saturation, Clear Fork Sandstone

Sample 2796A: Permeability 357 md; Effective Porosity 23.6%
Sample 2796B: Permeability 377 md; Effective Porosity 23.6%

Sample 2796A Four-Electrode Method			Sample 2796A Two-Electrode Method			Sample 2796B Four-Electrode Method		
Capillary Pressure psi	Brine Saturation Per Cent of Pore Volume	Resistivity Index $I = \rho/\rho_o$	Capillary Pressure psi	Brine Saturation Per Cent of Pore Volume	Resistivity Index $I = \rho/\rho_o$	Capillary Pressure psi	Brine Saturation Per Cent of Pore Volume	Resistivity Index $I = \rho/\rho_o$
	100	1.00		100	1.00		100	1.00
2	88.1	1.39	2	88.1	1.65	8	34.8	20.0
2	50.2	6.50	2	50.2	7.04	8*	30.5	29.9
2*	45.0	8.44	2*	45.0	10.5	16*	25.5	43.0
4	36.8	17.5	4	—	—	20	17.4	59.1
4*	33.9	24.4	4*	—	—	20*	13.1	63.9
8*	31.2	31.6	8*	31.2	33.0			
12	24.5	49.0	12	—	—			
12*	21.4	52.5	12*	—	—			
16*	19.1	55.0	16*	—	—			
20*	17.0	56.4	20*	17.0	53.5			

*Equilibrium saturation values

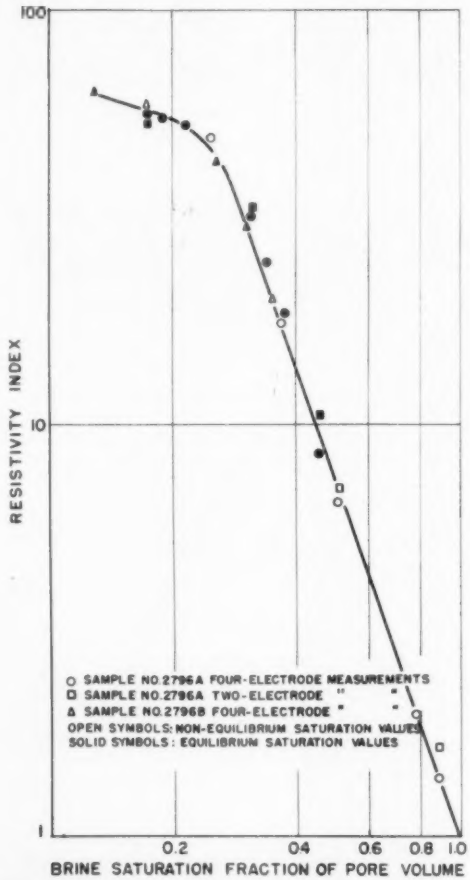

FIG. 8 — RESISTIVITY INDEX VS BRINE SATURATION, CLEAR FORK SANDSTONE. SAMPLE NO. 2796A: PERMEABILITY 357 md; EFFECTIVE POROSITY 23.6%. SAMPLE NO. 2796B: PERMEABILITY 377 md; EFFECTIVE POROSITY 23.6%.

sample is not contaminated by the presence of clays or other argillaceous matter, thereby complicating the measurement. The data (Table II) represent two independent runs on the same sample. During the first run both two- and four-electrode measurements were made. The open symbols represent non-equilibrium data points; the equilibrium data points are shown by solid symbols. It is evident that the reproducibility of the four-electrode data is good and that the four-electrode results agree well with those obtained by the two-electrode method. The sample is obviously one for which the saturation exponent is independent of saturation.

Another type of reproducibility test based on the data listed in Table III is illustrated in Fig. 8. Two adjacent plugs were drilled from a shaly sandstone. The values of the permeability and effective porosity for these two adjacent samples are nearly identical. Resistivity index determinations made for each sample with the four-electrode method show good agreement. Good agreement also exists between the four-electrode measurements and the two-electrode data taken on one of the samples. It appears that for both samples the saturation exponent is independent of saturation at the higher brine saturations. At the lower saturations, however, Archie's equation is no longer applicable. This lack of applicability may be attributed to the fact that, at the lower saturations, the resistance of the core matrix itself may be important. This effect has been noted by other investigators[6] and may be explained on the basis of conductive solids, such as shales, clays, and other colloidal matter capable of conducting electric current.

In order to extend these tests to the study of core samples longer than one inch, a combined interstitial water and resistivity cell similar to that shown in Fig. 2, was constructed and provided with four pairs of potential electrodes along the longitudinal axis of the cell. In this new form the resistivity cell accommodates a core sample three in. long. A schematic diagram of the electrode arrangement is shown in Fig. 9. Consecutive resistivity measurements were made on a "clean" sample with the four-electrode technique, using six different combinations of the potential electrodes. These electrode combinations are numbered, the spacing being 0.5 in. for combinations 1 through 4, and 1 in. for combinations 5 and 6. A two-electrode measurement across the total length of the core was also made. These data are listed in Table IV. Fig. 10 represents the computed resistivity indices plotted against saturation. The results for the two-electrode method are shown in Fig. 11. Both techniques yield essentially the same saturation exponent. Two other interesting observations may be made with regard to this experiment, the first being that the data

presented in Figs. 10 and 11 include indices computed both for equilibrium and non-equilibrium saturations.

This indicates that, for the samples investigated, during resistivity index measurements it was not necessary to attain saturation equilibrium unless a plot of the capillary pressure saturation curve was desired at the same time. This observation is consistent with numerous results obtained during routine measurements but not reported herein. Another point of interest is that, for this sample at least, the brine saturation distribution within the sample during the desaturation process remains essentially uniform, as indicated by the resistivity measurements made on various portions of the core sample. The two observations, while coincidental in these experiments, are of sufficient interest to deserve mention.

CONCLUSIONS

It is concluded, from the foregoing comparison of the two- and four-electrode methods as applied to formation resistivity factor and resistivity index determinations on the 60 core samples investigated:

1. That, provided proper techniques are employed either the two-electrode or four-electrode method will yield reliable resistivity values. Because of the different volumes of samples associated with each of the two methods of measurement, it is possible to measure, on any one sample, two equally reliable

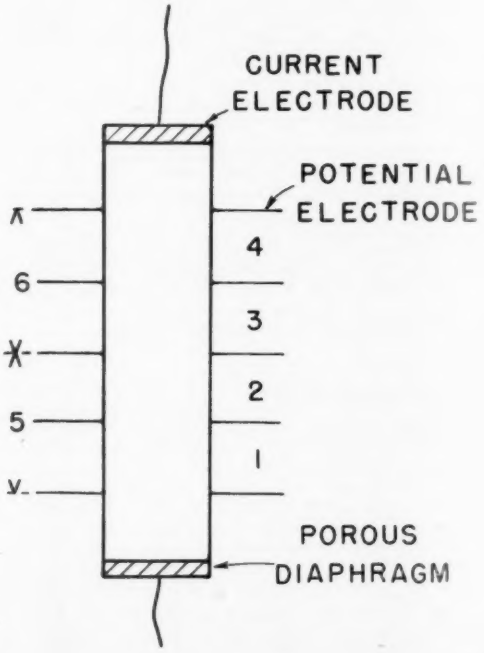

FIG. 9 — ELECTRODE ARRANGEMENT. LARGE CORE SAMPLE RESISTIVITY CELL.

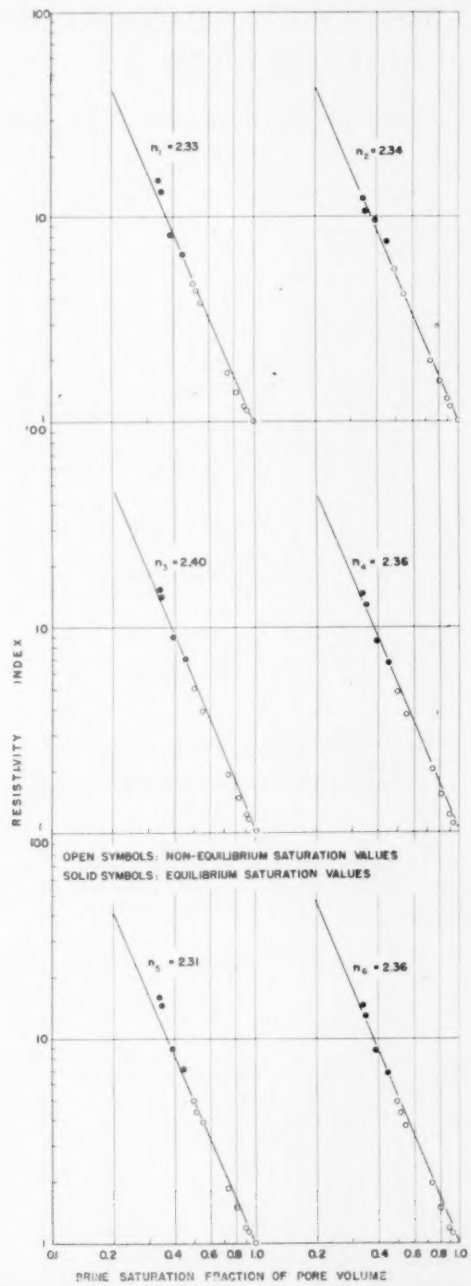

FIG. 10 — RESISTIVITY INDEX VS BRINE SATURATION. FOUR-ELECTRODE METHOD. WOODBINE OUTCROP. GAS PERMEABILITY 1130 md; EFFECTIVE POROSITY 38.8%.

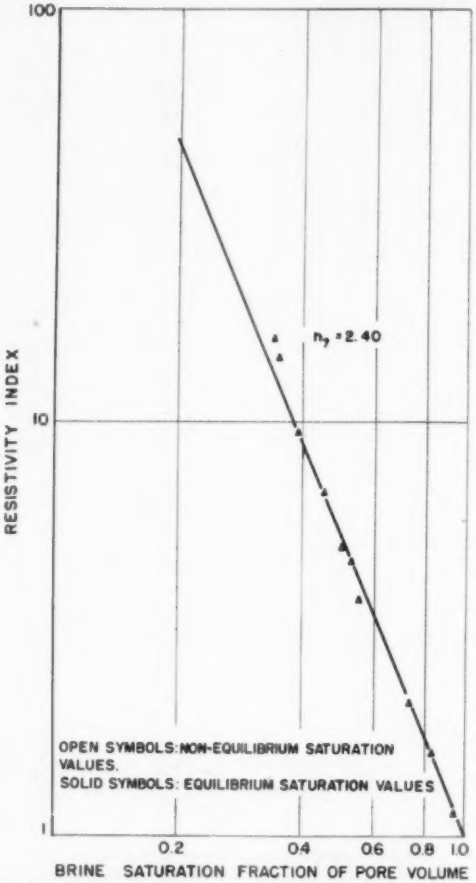

FIG. 11 — RESISTIVITY INDEX VS BRINE SATURATION. TWO-ELECTRODE METHOD. WOODBINE OUTCROP. NITROGEN PERMEABILITY 1130 md; EFFECTIVE POROSITY 38.8%.

but nevertheless different values of resistivity. Such differences will be an indication of non-homogeneity of the porous matrix. Since essentially equal values of resistivity were observed on the 60 core samples included in this investigation, it is concluded that these samples are essentially homogeneous insofar as electrical resistivity is concerned.

2. That, in determinations of the saturation exponent n, resistivity values at both equilibrium and non-equilibrium brine saturations may be used.

In all resistivity measurements it is unquestionably helpful to use both methods on the same sample, in order to check one measurement against the other. This is particularly desirable in resistivity index determinations.

ACKNOWLEDGMENT

Appreciation is expressed to the Magnolia Petroleum Co. and its management for permission to publish this paper.

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Table IV — Resistivity Index as a Function of Brine Saturation, Woodbine Outcrop
Permeability 1,130 md
Effective Porosity 38.8%

Capillary Pressure psi	Brine Saturation Per Cent of Pore Volume	Values of Resistivity Index: Four-Electrode Measurements Position** 1	Position** 2	Position** 3	Position** 4	Position** 5	Position** 6	Two-Electrode Measurements Position 7
	100	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	93.0	1.14	1.21	1.16	1.10	1.14	1.14	1.12
2	82.4	1.38	1.60	1.46	1.51	1.48	1.51	1.60
2	73.4	1.74	2.01	1.90	1.99	1.86	1.86	2.10
2	55.1	3.84	4.25	3.87	3.70	3.93	3.81	3.71
2	52.0	4.42	4.87	4.47	4.27	4.41	4.43	4.59
2	50.2	4.78	5.39	5.00	4.77	5.04	4.97	5.01
2*	44.9	6.60	7.60	6.96	6.63	7.09	6.92	6.69
4*	38.7	8.23	9.74	8.92	8.54	8.94	8.75	9.50
12*	34.7	13.5	10.8	13.5	12.8	14.6	13.2	14.4
20*	33.8	15.2	12.5	15.3	14.5	15.9	14.9	15.9
		$n_1 = 2.33$	$n_2 = 2.34$	$n_3 = 2.40$	$n_4 = 2.36$	$n_5 = 2.31$	$n_6 = 2.36$	$n_7 = 2.40$

*Equilibrium saturation values
**Refer to Fig. 9 for location of measurement positions along sample

USE OF ACTIVATED CHARCOAL IN CEMENT TO COMBAT EFFECTS OF CONTAMINATION BY DRILLING MUDS

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ABSTRACT

Results of laboratory investigations of the effects of drilling muds on oil well cements are presented which show that relatively large quantities of untreated muds do not seriously interfere with the setting of cement slurries, but that relatively small quantities of treated muds seriously retard the setting of cement slurries. Laboratory results also indicate that the harmful effects of contamination with treated muds can be counteracted by the addition of activated charcoal to cements. Also described is the successful use of cement containing activated charcoal for the placement of plugs in open hole after previous attempts with ordinary cement had been unsuccessful.

INTRODUCTION

The contamination of cement slurry by dilution with drilling mud has long been considered a cause of failure in oil well cementing. The cement slurry must displace the drilling mud from the annulus between the casing and the walls of the borehole, and it is probable that some mixing of the slurry and the mud occurs even under the most nearly ideal displacement conditions. Hole enlargement, failure to center the casing in the hole, and formation of gel structure in the drilling mud increase the probability of contamination. In some cementing operations, such as the placement of a cement plug in open hole, considerable mixing of the mud and slurry is likely. Many cement failures which can be attributed logically to no cause other than contamination of the cement slurry by the mud attest the need of a better understanding of this problem.

Considerable attention was given to the problem of mud contamination of cements about 20 years ago.[1,2,3,4] The effects of field mud upon cement slurries prepared with different amounts of mix water were investigated thoroughly, and the data obtained were invaluable in determining the causes of the high percentage of failure in oil-well cementing at that time and in bringing about improved cementing results. Since then, many aspects of the problem have changed, due primarily to advancements in cement and drilling mud technology. Today, several types of portland cement are used in well cementing and numerous chemical additives are used in drilling muds. An excellent report on the effects of drilling mud additives on oil-well cements was issued during 1951 by the American Petroleum Institute.[4] Data in the report revealed that many mud additives, notably organic materials in relatively small amounts, produce a marked effect on the properties of cements. Prior to this time, little information has been available on the effects of chemicals commonly used in the treatment of drilling muds upon the properties of cements. Another aspect of the problem of mud contamination of cements, which has received no attention heretofore, is the possibility of producing a cement having properties unaffected by a reasonable amount of mud contamination.

In view of the need for additional information on the contamination of present-day cements by currently-used drilling muds, the investigation described herein was initiated several years ago with a two-fold purpose: first, to determine the capacity of cement slurries to tolerate contamination by both untreated and treated muds without loss of ability to set and develop strength within a reasonable time; and, second, to investigate the possibility of enhancing the ability of cement slurries to withstand mud contamination by incorporating additives in the cement. The data for this study were obtained by mixing drilling mud with cement slurry and testing the resulting slurry-mud mixture for rate of set and development of strength. Also, several materials were tested for their possible improvement of the property of cement slurry to withstand mud contamination; these materials were tested in both contaminated and uncontaminated cement slurries.

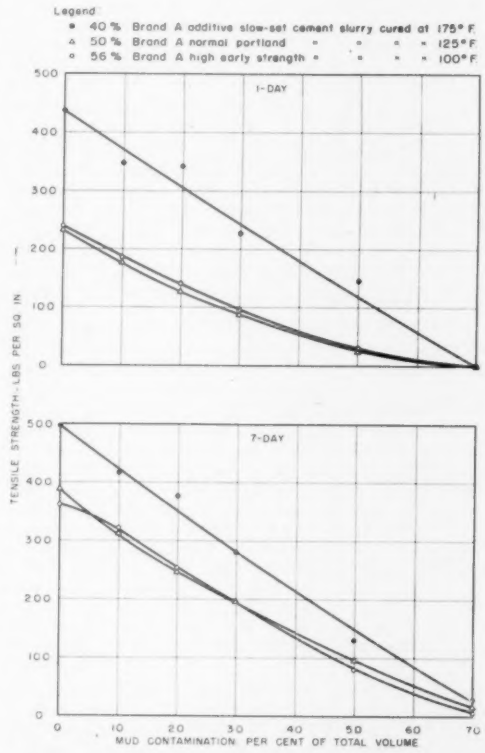

FIG. 1 — EFFECT OF MUD CONTAMINATION ON TENSILE STRENGTHS OF THREE TYPES OF OIL-WELL CEMENTS. UNTREATED FIELD MUD FROM WELL IN FORT BEND COUNTY, TEXAS.

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office June 19, 1952.
Paper presented at the Houston meeting, Oct. 1-3, 1952.

LABORATORY INVESTIGATION OF MUD CONTAMINATION OF CEMENTS

Effect of Untreated Mud on the Strength Development of Cements

The first series of tests was performed to determine the capacity of three types of oil-well cements, *i.e.*, highly early strength, normal portland, and slow-set, to tolerate contamination by an untreated mud without loss of ability to develop strength within a reasonable time.

The effect of contamination on the tensile strength of the cements was determined by adding to the cement slurries an untreated field mud in concentrations of 10, 20, 30, 50, and 70 per cent by volume of the total slurry-mud mixture. Given volumes of cement slurry and drilling mud were mixed together by hand for one minute and the resulting mixtures were poured into briquet molds. After the briquets were aged under water for one and for seven days, respectively, tensile strength measurements were made.

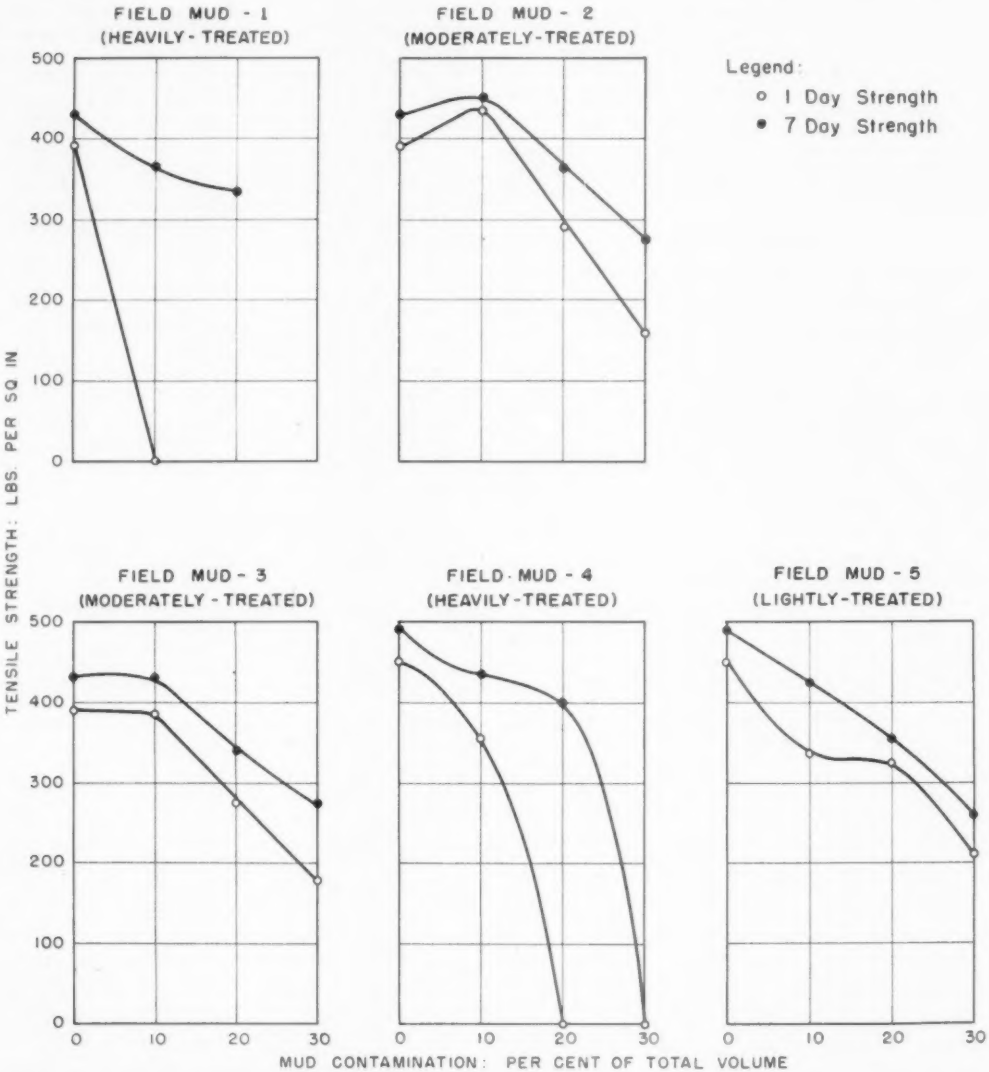

FIG. 2 — EFFECT OF MUD CONTAMINATION ON TENSILE STRENGTH OF A SLOW-SET CEMENT. MUD ADDED TO 40% SLURRY OF BRAND "A" ADDITIVE SLOW-SET CEMENT. TEST TEMPERATURE: 175°F.

Table I — Treated Muds Used in Cement Contamination Tests

Mud	Chemicals in Mud							Days Drilling	Depth Ft
	NaOH	Quebracho	Lime	SAPP	Starch	Dry Tan[a]	Red Mud[b]		
	Total added to mud system, lb								
Field-1	8,900	12,050	6,500	—	19,875	—	—	113	10,000
Field-2	1,450	3,175	500	1,225	—	—	3,282	45	10,176
Field-3	1,350	2,600	—	—	—	4,300	912	19	9,623
Field-4[c]	4,375	7,150	2,890	—	—	—	—	79	9,931
Field-5	—	—	—	—	—	—	486	93.2	8,960
	Added to 7% bentonite clay suspension, lb/bbl								
Lab-1	0.1	0.1	—	—	—	—	—	—	—
Lab-2	1	1	—	—	—	—	—	—	—
Lab-3	2	2	—	—	—	—	—	—	—

[a]Dry mixture of equal portions of quebracho, lime, and sodium carbonate.
[b]Chemical solution of caustic-quebracho.
[c]Mud system changed to caustic, quebracho, lime mud 25 days prior to sampling. Workover job in cased hole.

These results, presented in Fig. 1, show the comparative effects of mud contamination on the one-day and seven-day tensile strengths of the three types of oil-well cements. The strength of the cements decreased as the mud concentration increased to 70 per cent of total volume. At 70 per cent mud concentration, all of the mixtures developed very little or no tensile strength. At mud concentrations less than 70 per cent, slurry-mud mixtures prepared with the slow-set cement developed greater one-day strengths than slurry-mud mixtures prepared with either the high early strength or the normal portland cement. For example, the slow-set cement slurry containing 50 per cent mud by total volume had a greater one-day tensile strength than did the high early strength and normal portland cement slurries contaminated with 30 per cent mud by total volume. All cements tested, however, developed sufficient one-day strength to produce a satisfactory set cement even when contaminated with as much as 30 per cent mud by total volume.

These data indicate that the contamination of cement slurries with untreated drilling mud is probably not a serious problem.

Effect of Treated Muds on the Strength Development of Cements

A second series of tests was made to determine the capacity of cement slurries to withstand contamination by treated muds. This second series of tests was divided into two groups. One group of tests was made using field muds obtained from wells drilling in the Gulf Coast area of Texas. Since it was not practical to ascertain the concentration of the chemicals in the field muds, another group of tests was made using laboratory-prepared muds treated with known concentrations of caustic-quebracho or starch. These two treating agents were selected because they are used very extensively in field operations. Pertinent data on the muds are presented in Table I. Since chemically treated muds are generally used at depths where slow-set cements are required, these tests were made using a slow-set cement.

The tests were made by mixing the muds separately in concentrations of 10, 20, and 30 per cent by total volume of cement slurry-mud mixture, and determining the strength development of the resulting mixtures. The slurry-mud mixtures were poured into briquet molds, the briquets were aged under water at 175°F for periods of one and seven days, removed, and tested for tensile strength.

Results Using Field Muds

Data obtained by use of the field muds as contaminants, presented in Fig. 2, indicated that the contamination of cement slurries with some field muds may seriously affect the cement job.

Addition of 10 per cent of Field Mud 1, which had been heavily treated with caustic, quebracho, lime, and starch, retarded set so that no strength was developed at the end of one day. Field Mud 4, which also had been heavily treated with caustic, quebracho, and lime, had less effect upon early strength development. The addition of 10 per cent of the latter mud caused some reduction in one-day tensile strength, and the addition of 20 per cent of this mud retarded set so severely that no strength was developed at the end of one day. A slurry containing 30 per cent of Field Mud 4 failed to set even after seven days. Contamination with the other field muds, which were only moderately or lightly treated, caused less pronounced retardation of the strength development of the cement.

Results Using Laboratory Muds

Data obtained by use of laboratory-prepared muds containing caustic-quebracho, presented in Fig. 3, showed that heavily treated caustic-quebracho mud seriously retarded the strength of cement, but that moderately treated caustic-quebracho muds did not seriously affect the cement. A cement slurry-mud mixture containing 20 per cent of a mud treated with two lb caustic and two lb quebracho per bbl failed to set in one day, and one containing 30 per cent of this mud failed to set after seven days. Slurry-mud mixtures containing as much as 30 per cent mud treated with smaller concentrations of these chemicals (one lb/bbl of each chemical, and 0.1 lb/bbl of each chemical, respectively), developed reasonable tensile strengths in one day.

Data obtained by use of laboratory-prepared muds containing starch, presented in Fig. 4, showed that starch muds seriously retarded the strength development of cement. Twenty to 30 per cent contamination with muds containing fresh starch produced slurry-mud mixtures which failed to set in one day. All of these mixtures, however, developed reasonable tensile strengths after aging seven days. The fermented starch muds had a more pronounced effect upon the one-day strengths than did the fresh starch muds, but the effects of the fermented starch and fresh starch muds upon the seven-day strengths were about the same.

Effect of Treated-Mud Contamination on the Strength Development of Different Slow-Set Cements

Conventional slow-set cements are of two types: the straight non-additive type, in which the slow-setting property is due principally to the adjustment of the raw components in the cement clinker, and the additive type, in which the slow-setting property is due principally to the addition of a small amount of organic material or combination of materials to the cement. These additive materials are called "retarders." The data on

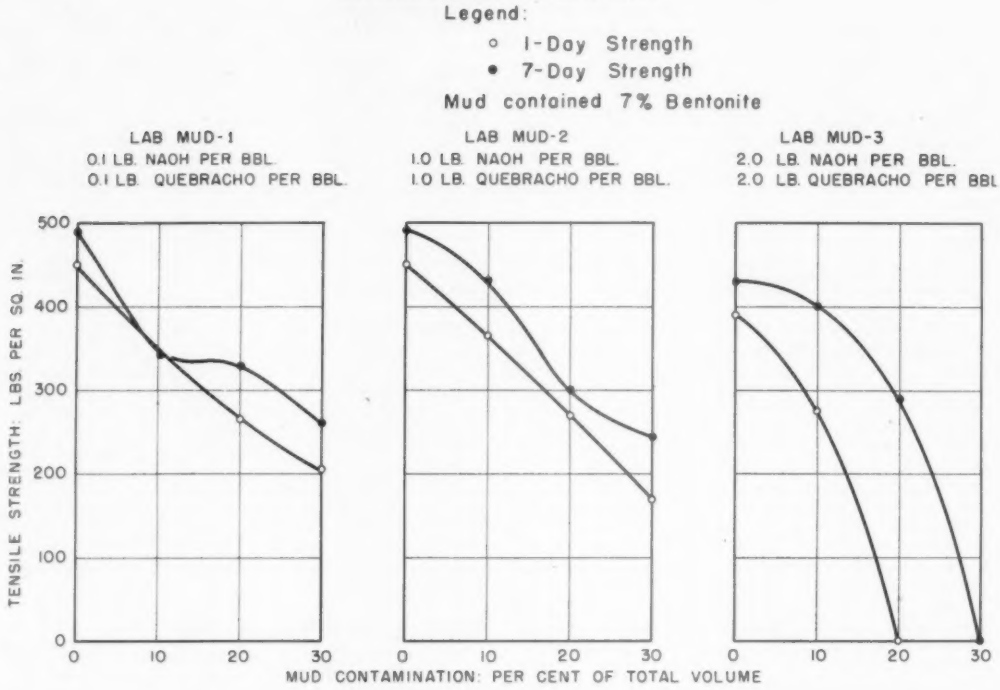

FIG. 3 — EFFECT OF MUD CONTAMINATION ON TENSILE STRENGTH OF A SLOW-SET CEMENT. MUD ADDED TO 40% SLURRY OF BRAND "A" ADDITIVE SLOW-SET CEMENT. TEST TEMPERATURE: 175°F.

slow-set cement presented heretofore in this paper were obtained using an additive-type cement. Results obtained using one slow-set cement do not necessarily indicate that similar results will be obtained using other slow-set cements, because different retarders are used in different brands of additive slow-set cements and no retarder is used in straight slow-set cements. In view of these differences in slow-set cements, it seemed advisable to investigate the effect of treated-mud contamination upon the properties of several slow-set cements. Accordingly, slurries prepared from three additive slow-set cements and one straight slow-set cement were contaminated with a mud heavily treated with both caustic-quebracho and starch. The slurry-mud mixtures, containing 16.7 per cent mud by total volume, were aged under water at 175°F and observed for setting and strength development.

The results, presented in Table II, showed that two of the additive slow-set cements failed to set at 175°F even after seven days when the slurries were contaminated with 16.7 per cent mud by total volume. Under similar curing conditions and with a like amount of contamination, the straight slow-set cement and one of the additive slow-set cements developed reasonable strength within four days. This information indicates that straight slow-set cements may be affected less severely by treated muds than some additive slow-set cements. The results suggest that the retarders used in slow-set cements may be responsible for the difference in the effect of treated-mud contamination on different additive slow-set cements.

Effect of Temperature on the Strength Development of Cement Slurries Contaminated with Treated Mud

Tests were made to determine the effect of temperature on the strength development of cement slurries contaminated with treated muds. To this end, several laboratory-prepared muds containing 1:1 caustic-quebracho in concentrations of 1.9, 2.8, 3.6, and 4.3 lb of each chemical per bbl of mud were used to contaminate slurries of two cements. These muds were added to slurries of an additive slow-set cement and a straight slow-set cement in concentration of 16.7 per cent of total volume. The results of the tensile strength measurements made on

Table II — Effect of Treated-Mud Contamination on Strength Development of Four Slow-Set Cements

Brand of Cement	Water Content of Slurry, cu cm water/100 gm cement	Mud Contamination[a], Vol. Per Cent	Tensile Strength psi[b], 3 days	Tensile Strength psi[b], 4 days
A[c]	40	16.7	0	150
B[c]	40	16.7	0	0[d]
C[c]	40	16.7	0	0[d]
D[e]	40	16.7	0	160

[a] Untreated field mud from well in Harris County, Tex., was treated in laboratory with 3 lb quebracho, 3 lb caustic, and 10 lb pre-gelanitized starch per bbl of mud 3 days prior to start of tests. No odor of fermentation noted.
[b] Test specimens cured under water at 175°F.
[c] Additive slow-set cement.
[d] Not to initial set at end of 7 days.
[e] Straight slow-set cement.

these slurry-mud mixtures after curing under water at temperatures of 150, 175, and 200°F are presented in Table III.

The data showed that, as the curing temperature of the slurry-mud mixtures was lowered from 200°F, the retardation effect of the caustic-quebracho mud upon the setting and strength development properties was more pronounced. The straight slow-set cement slurry contaminated with 16.7 per cent mud containing 2.8 lb caustic and 2.8 lb quebracho per bbl developed a tensile strength of 223 psi in one day when cured at 200°F. The same slurry-mud mixture failed to set in one day when cured at 175 and 150°F. With the additive slow-set cement, a like retardation was noted for a similar composition when the curing temperature was lowered.

The results showed also that increasing the amount of caustic-quebracho in the mud resulted in retardation of the strength development of the slurry-mud mixtures. This retardation effect was greater for the additive slow-set cement than for the straight slow-set cement when the mud contained more than 2.8 lb each of caustic and quebracho per bbl. For instance, the slurry-mud mixture prepared with the straight slow-set cement developed a tensile strength of 140 psi in one day at a curing temperature of 200°F when contaminated with 16.7 per cent mud by volume which contained 4.3 lb caustic and 4.3 lb quebracho per bbl. Under similar test conditions, the slurry-mud mixture prepared with the additive slow-set cement did not set in one day and developed a tensile strength of only 50 psi after curing for two days. Since the additive slow-set cement used in these tests was the one least affected by treated-mud contamination in tests presented previously in Table II, it appears that a straight slow-set cement may be superior to an additive slow-set cement in its ability to withstand contamination by heavily treated muds.

It is significant to note that the cement slurry-drilling mud mixtures developed about the same strengths after aging seven days, regardless of the amount of caustic-quebracho present in the mud. This shows that the action of the caustic-quebracho in the mud is one of retardation of set of the cement rather than reduction of ultimate strength development.

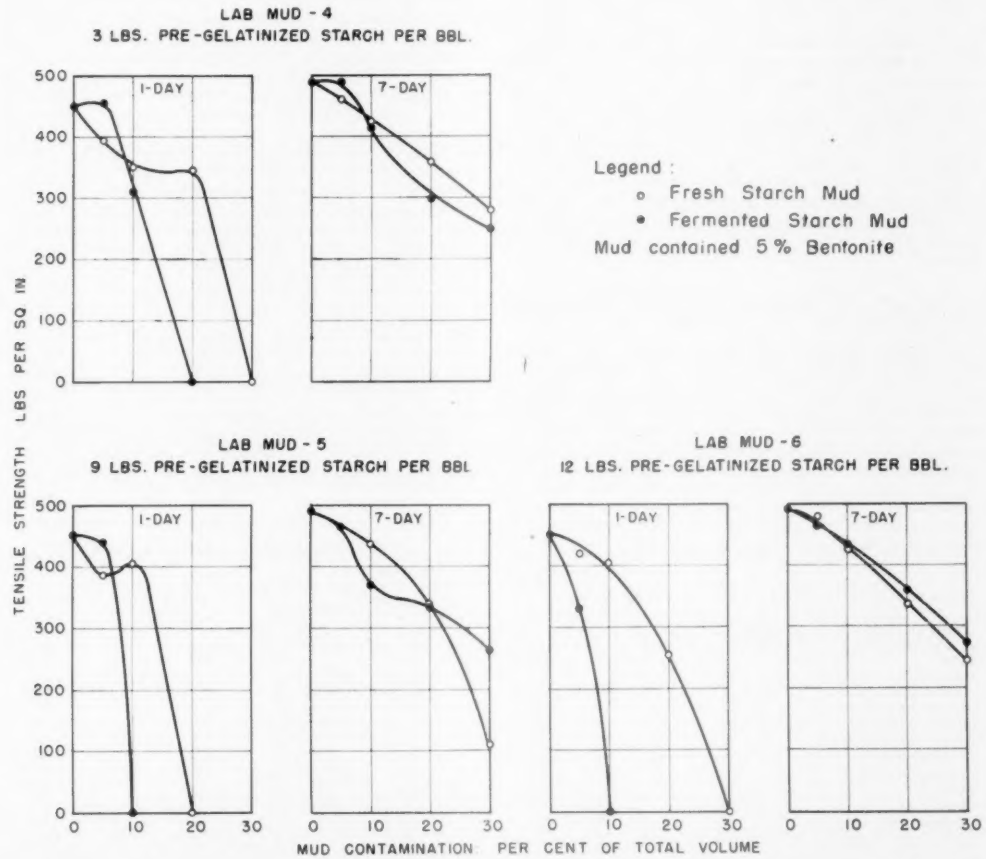

FIG. 4 — EFFECT OF MUD CONTAMINATION ON TENSILE STRENGTH OF A SLOW-SET CEMENT. MUD ADDED TO 40% SLURRY OF BRAND "A" ADDITIVE SLOW-SET CEMENT. TEST TEMPERATURE: 175°F.

Table III — Effect of Temperature on Tensile Strength Development of Slow-Set Cements Contaminated with Caustic-Quebracho Muds

Mud Contamination	Concentration of Caustic and Quebracho[a]	Tensile Strength, psi					
		150°F		175°F		200°F	
Vol. Per Cent	lb each/bbl	1 day	7 days	1 day	7 days	1 day	7 days
Brand "A" Additive Slow-Set Cement (40 per cent slurry)							
16.7	1.9	173	330	150	330	No test made	No test made
16.7	2.8	0	330	0	330	223	260
16.7	3.6	No test made	No test made	0	320	0	305
16.7	4.3	No test made	No test made	0	0	0	280
Brand "D" Straight Slow-Set Cement (40 per cent slurry)							
16.7	1.9	110	283	151	342	260	345
16.7	2.8	0	358	0	325	205	310
16.7	3.6	No test made	No test made	0	313	156	263
16.7	4.3	No test made	No test made	0	330	140	301

[a]In 6 per cent bentonite clay suspension.

LABORATORY INVESTIGATION OF THE COUNTERACTION OF MUD CONTAMINATION OF CEMENTS

The second phase of the work was undertaken in an effort to enhance the ability of cement slurries to withstand mud contamination. Data presented previously have shown that cement slurries contaminated with 30 to 50 per cent untreated mud (by total volume) developed sufficient one-day tensile strengths for a good cement job, whereas cement slurries contaminated with only 10 to 20 per cent mud which was heavily treated with caustic-quebracho or starch failed to set within one day. It appeared, therefore, that the deleterious effect of treated-mud contamination might be eliminated if the treating agents in the mud were rendered inactive at the time of contamination. It was thought that this might be accomplished by either the precipitation or the adsorption of the mud treating agents by the addition of suitable materials to the cement.

Investigation of Additives to Combat Treated-Mud Contamination of Cement Slurries

Preliminary tests were made for the purpose of evaluating the usefulness of various materials as cement additives in enhancing the ability of cement slurries to withstand contamination with a mud treated with caustic-quebracho. These materials were tested by mixing each with dry cement (a straight slow-set), forming slurries by the addition of suitable amounts of water, and mixing the resulting slurries with laboratory-prepared muds containing caustic-quebracho. The mixtures were then aged under water at 175°F and observed for set time or tested for strength development. To determine the effect of each additive upon the properties of the cement slurry containing no mud, similar tests were made on a neat cement slurry containing no mud, and on a cement slurry containing each test additive and no mud. The materials tested included contact clays, bentonite, Attapulgite clays, diatomaceous earths, aluminum oxide, activated bauxites, sodium silicates, activated magnesium silicate, silica gels, synthetic resins, a variety of carbonous substances, and numerous inorganic chemicals.

These preliminary tests revealed that calcium hydroxide, activated charcoal, and several clays showed promise in accelerating the set and strength development of cement slurries containing caustic-quebracho mud without appreciably affecting the strength properties of the uncontaminated cement slurry. Therefore, more detailed laboratory information was obtained on the use of these additives. The test results are presented in Table IV. A special contact clay, which was the most promising clay tested, was used in these tests.

The results of tensile strength measurements showed that either calcium hydroxide or activated charcoal was more effective in increasing the early strength of cement slurry-drilling mud mixtures than was the contact clay. However, pumpability tests showed that the addition of calcium hydroxide in an amount sufficient to cause early strength development of the contaminated slurry reduced the thickening time of the uncontaminated cement slurry. On the other hand, the addition of sufficient activated charcoal to effect early strength develop-

Table IV — Effect of Calcium Hydroxide, Charcoal, and Clay on Tensile Strength of Cement with and without Caustic-Quebracho Mud Added

Substance Added to Dry Cement[a]	Wt. Per Cent (Based on Cement)	Water Content of Slurry cu cm Water/100 gm Cement	Mud Contamination[b] Vol. Per Cent	Consistency RPM at 400 gm Stormer	Tensile Strength, psi[c] 1 day	2 days	7 days
None	0	40	0	750	331	—	525
None	0	40	16.7	1,090	0	0	313
Calcium hydroxide	2	43	0	920	301	—	393
Calcium hydroxide	2	43	16.7	1,090	0	167	325
Calcium hydroxide	5	43	0	750	341	—	425
Calcium hydroxide	5	43	16.7	950	145	—	362
Activated charcoal	5	43	0	720	363	—	520
Activated charcoal	5	43	16.7	1,090	123	—	362
None[d]	0	40	0	770	205	—	618
None[d]	0	40	16.7	920	0	—	373
Special contact clay[d]	5	43	0	380	265	—	477
Special contact clay[d]	5	43	16.7	860	0	175	423

[a]Brand "D" straight slow-set cement.
[b]Six per cent bentonite mud containing 3.6 lb sodium hydroxide and 3.6 lb quebracho per bbl.
[c]Test specimens cured under water at 175°F.
[d]Different bag of cement used for these tests.

Table V — Effect of Various Concentrations of Activated Charcoal on Strength Development of Cement Slurry Contaminated with Caustic-Quebracho Mud

Charcoal Added Wt. Per Cent (Based on Cement[a])	Water Content of Slurry cu cm Water/100 gm Cement	Mud Contamination[b] Vol. Per Cent	Tensile Strength, psi[c] 1 day	2 days
0.0	40	16.7	0	0[d]
0.2	40	16.7	0	0[d]
0.5	40	16.7	0	165
1.0	40	16.7	0	168
5.0	40	16.7	108	—
10.0	43	16.7	112	—
20.0	50	16.7	73	—

[a]Brand "D" straight slow-set cement.
[b]Untreated field mud from well in Harris County, Tex., was treated in laboratory with 4 lb sodium hydroxide and 4 lb quebracho per bbl of mud.
[c]Test specimens cured under water at 175°F.
[d]Not set within 4 days.

ment of the contaminated slurry did not change appreciably the thickening time of the uncontaminated slurry. Since it may be dangerous on some jobs to add a material which reduces the thickening time of cement slurry, it appeared that activated charcoal was the most promising additive of the three for combating the deleterious effect of cement contamination by muds containing caustic-quebracho. Attempts to produce a composition containing cement and various combinations of calcium hydroxide, clay, and activated charcoal which would be superior to a composition containing cement and activated charcoal were unsuccessful.

Amount of Activated Charcoal Needed to Counteract Treated-Mud Contamination of Cement Slurries

To determine the optimum concentration of activated charcoal to counteract the deleterious effect of treated-mud contamination, slurries of a straight slow-set cement were prepared and tested which contained 0, 0.2, 0.5, 1, 5, 10, and 20 per cent charcoal by weight of dry cement. These slurries were mixed with a mud containing four lb caustic and four lb quebracho per bbl in the concentration of 16.7 per cent mud by total volume. The briquets were aged under water at 175°F and their tensile strengths measured after the mixtures had set.

The results, presented in Table V, showed that less than 0.5 per cent charcoal was not satisfactory in accelerating the strength development of the slurry-mud mixtures. Increase of charcoal content up to 10 per cent resulted in increase of early strength. From a practical standpoint, it appeared that the optimum charcoal concentration was about five per cent for this particular charcoal. Smaller concentrations of a more highly activated charcoal may be used.

Counteraction of Contamination of Cement Slurries with Muds Containing Various Treating Agents

Since it was found that the retardation of strength development caused by caustic-quebracho muds could be largely counteracted by the addition of activated charcoal to the cement, it was thought that charcoal might be effective also in counteracting the retardation effect of other mud treating agents, especially starch. Accordingly, tests were made to determine the effect of the addition of muds containing starch, calcium lignosulfonate, and sodium acid pyrophosphate on the strength development of cement slurries, and to determine if the addition of activated charcoal to the cement would counteract any deleterious effects caused by these chemicals in the mud.

For this investigation, slurries were prepared with a straight slow-set cement, both with and without the addition of activated charcoal. Tensile strength tests were made on the uncontaminated slurries and on slurries contaminated with muds which had been treated separately with starch, calcium lignosulfonate, and sodium acid pyrophosphate.

The results of these tests, presented in Table VI, indicated the following:

1. Muds treated with starch which had fermented seriously retarded the strength development of cement slurries, and the addition of activated charcoal was effective in counteracting contamination by such a mud.

2. Muds heavily treated with calcium lignosulfonate seriously retarded the set of cement slurries, and the addition of activated charcoal was effective in counteracting contamination by muds containing calcium lignosulfonate.

3. Muds heavily treated with sodium acid pyrophosphate did not cause serious retardation of the set of cement slurries.

Effect of Activated Charcoal on the Pumpability of Cements

Information presented previously has shown that the addition of activated charcoal to a straight slow-set cement accelerated the strength development of the slurry contaminated with treated muds without adversely affecting the pumpability of the uncontaminated slurry. Many of the slow-set cements on the market, however, are additive type cements; they obtain their slow-setting property by the addition of small quantities of organic substances. In order to investigate the possibility that activated charcoal might adsorb these substances in additive slow-set cements and thereby reduce their pump-

Table VI — Effect of Treated Muds on Strength Development of Cement Slurry with and without Activated Charcoal Added

Charcoal Added Wt. Per Cent (Based on Cement[a])	Water Content of Slurry cu cm Water/100 gm Cement	Type of Treating Agent Added to Mud[b]	Concentration of Treating Agent in Mud lb/bbl	Mud Contamination Vol. Per Cent	Tensile Strength, psi[c] 1 day	2 days	7 days	30 days
0	40	None	0	0	195	—	—	570
5	40	None	0	0	272	—	—	573
0	40	Starch[d]	10	16.7	0	160	—	—
5	40	Starch[d]	10	16.7	103	250	—	—
0	40	SAPP[e]	5	16.7	159	—	—	—
5	40	SAPP[e]	5	16.7	157	—	—	—
0	40	SAPP[e]	10	16.7	164	—	—	—
5	40	SAPP[e]	10	16.7	181	—	—	—
0	40	Lignin[f]	12	16.7	0	0[g]	415	—
5	40	Lignin[f]	12	16.7	0	102	425	—

[a]Brand "D" straight slow-set cement.
[b]Untreated field mud from well in Harris County, Tex., used as base mud.
[c]Test specimens cured under water at 175°F.
[d]A pre-gelatinized starch. Mud was well-fermented when tested.
[e]Sodium acid pyrophosphate, commercial grade, obtained from field sample.
[f]Calcium lignosulfonate.
[g]Not set within 4 days.

Table VII — Effect of Activated Charcoal on Pumpability of Cements

Cement Tested	Charcoal Added	Water Content of Slurry	Thickening Time			
			Schedule 5[a]		Schedule 8[b]	
	Wt. Per Cent (Based on Cement)	cu cm Water/100 gm Cement	hr	min	hr	min
Normal Portland — Brand "B"	0	46	1	50	—	—
Normal Portland — Brand "B"	5	53	1	47	—	—
Normal Portland — Brand "E"	0	46	2	30	—	—
Normal Portland — Brand "E"	5	53	2	30	—	—
Straight Slow-Set — Brand "D"	0	40	—	—	1	50
Straight Slow-Set — Brand "D"	5	43	—	—	1	50
Additive Slow-Set — Brand "A"	0	40	—	—	2	46
Additive Slow-Set — Brand "A"	5	43	—	—	2	32
Additive Slow-Set — Brand "B"	0	40	—	—	2	40
Additive Slow-Set — Brand "B"	5	43	—	—	1	40

[a]Tested according to API Code 32 for 8,000 ft well depth.
[b]Tested according to API Code 32 for 14,000 ft well depth.

ability, pumpability tests were made on two additive slow-set cements, one straight slow-set cement, and two normal portland cements.

The results, presented in Table VII, showed that the thickening times of slurries prepared with the normal portland cements and the straight slow-set cement were not changed appreciably by the addition of activated charcoal. The thickening time of one of the additive slow-set cement slurries was reduced only slightly but the thickening time of the other additive slow-set cement slurry was reduced quite drastically. From these data, it appears that satisfactory cementing compositions containing activated charcoal may be prepared with either normal portland cements or straight slow-set cements but that activated charcoal should not be added to additive-type slow-set cements without checking its effect upon the pumpability of the particular cement prior to its use.

FIELD USE OF CEMENT CONTAINING ACTIVATED CHARCOAL

Cement containing activated charcoal has been used in two field jobs for the purpose of setting cement plugs in a well drilling in Tyler County, Tex. Attempts to recover 150 ft of drill collars and bit which had been left in the hole at a depth of 10,775 ft had been unsuccessful and it was decided to sidetrack around them. Four cement jobs using conventional slow-set cements in an effort to obtain a firm plug on which to set a whipstock to sidetrack the hole were unsuccessful, apparently due to the failure of the cement to set firmly. Soft cement was washed out after each job. It was thought that the mud in use, which was an oil-emulsion mud treated with quebracho, caustic, and sodium acid pyrophosphate, might be deleteriously affecting the cement and that the addition of activated charcoal to the cement might alleviate the trouble. The fifth cement plug was placed, therefore, with 100 sacks of straight slow-set cement containing 500 lb of activated charcoal. Twenty hours later the top of the cement plug was located and medium hard cement was drilled from 10,462 to 10,476 ft. An attempt to sidetrack at this point was unsuccessful. The hole was reamed and drilled to 10,525 ft and successfully sidetracked to 10,559 ft where a survey showed that the hole was five degrees off vertical. During subsequent drilling, however, the pipe worked back into the old hole, resulting in the necessity of setting another plug. The next plug was placed with 200 sacks of straight slow-set cement containing 500 lb of activated charcoal. The top of the cement plug was located at 10,232 ft and medium hard cement was drilled to 10,291 ft 28 hours after placement. The hole was successfully sidetracked at 10,305 ft and subsequently drilled to total depth in the new deviated hole.

These field jobs were done on short notice and time was not taken to core the set cement and to obtain other data which would have been helpful in evaluating the effectiveness of the activated charcoal. A more detailed program to evaluate the usefulness of cements containing activated charcoal in the field is planned.

CONCLUSIONS

The conclusions reached from consideration of the information presented may be summarized as follows:

1. Contamination of cement slurries with untreated drilling mud in concentrations likely to occur in the cementing of wells does not seriously affect the properties of cements. The contamination of cement slurries with untreated field muds, therefore, is probably not a serious problem.

2. Contamination of cement slurries with treated muds may cause serious retardation of the set of cements. This retardation effect caused by the mixing of treated muds with cement slurries may result in the failure of some cement jobs.

3. Straight slow-set cement appears to be superior to additive slow-set cement in its ability to withstand contamination with treated muds.

4. The retardation effect caused by the contamination of cement slurries with treated muds is more pronounced at low temperatures than at high temperatures. Mud contamination may be more critical, therefore, in wells of moderate depth than in extremely deep wells.

5. The deleterious effects of the contamination of cement slurries with treated muds may be partially counteracted by the addition of activated charcoal to the cement.

6. Satisfactory cementing compositions containing activated charcoal may be prepared with either normal portland cement or straight slow-set cement but activated charcoal should not be added to additive slow-set cement without prior checking of its effect upon the pumpability of the particular cement.

7. Cement containing activated charcoal has been used successfully in the field for the placement of two cement plugs in open hole.

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THE SLIP VELOCITY OF GASES RISING THROUGH LIQUID COLUMNS

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ABSTRACT

This paper presents the results of a study of the slip velocity of gases rising through liquids in vertical tubes, inclined tubes, and vertical annuli. The data were obtained in gas-liquid systems which included combinations of air, propane and natural gas (over 97 per cent methane) with water, lubricating oils, and crude oils. The 214 data points obtained in this study along with 11 data points reported in the literature are incorporated in an empirical correlation which relates the mean slip velocity of gases flowing through liquids with the parameters gas rate, tube size, ratio of liquid viscosity to liquid density, gas density, liquid density, and the angle of the tube from the vertical.

The average numerical deviation of the measured slip velocity data from values obtained from the correlation is 9.2 per cent. The average algebraic deviation between measured and predicted data is 0.31 per cent, an indication that the correlation is a satisfactory representation of the data.

The correlation presented in this paper will be useful primarily in the design of subsurface gas-oil separation equipment for increasing the efficiency of oil-well pumping installations, but may perhaps be extended to other situations of gases rising through liquid columns.

INTRODUCTION

The production of oil by pumping is often complicated by the presence of free and dissolved gas in the oil at bottom-hole conditions. This gas can be drawn into the pump barrel and result in "vapor locking" the pump, thus reducing the efficiency of the pumping operation. Large amounts of free gas may be excluded from the pump by the use of a gas-anchor, which is designed to allow the separation of free gas from the oil before it is drawn into the pump. The design of a suitable gas-anchor depends on a knowledge of the difference between the velocity of the free gas and that of the oil as the oil travels down toward the pump intake. This rate of gas rise through the oil is termed "slip velocity."

As a first step toward the full understanding of this problem, the mean slip velocities of gases flowing through static

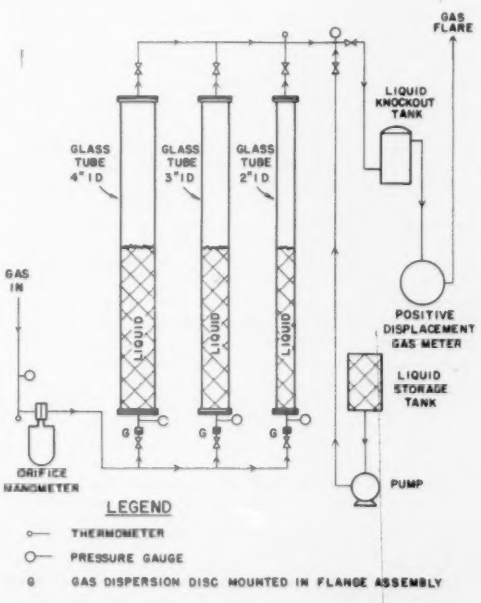

FIG. 1 — SLIP VELOCITY APPARATUS, SCHEMATIC DIAGRAM.

[1]References given at end of paper.

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heads of liquids were measured and the data correlated. The correlation is presented in this paper.

PROCEDURE AND EQUIPMENT

In the past, a number of different techniques have been used to determine the rate at which gases rise through liquids. A dynamic method was employed by Moore and Wilde,[1] which involved the simultaneous metered circulation of both gas and liquid through vertical pipes. At an arbitrarily chosen time interval after the start of this operation, two quick-closing valves, one at the bottom and the other at the top of the pipe being tested, were closed. The volumes of gas and liquid caught in the pipe were measured, and from this information and the known rates of flow the slip velocity of the gas was calculated. In these calculations it was assumed that the relative portions of the cross-sectional area of the pipe occupied by the gas and liquid streams were directly related to the volume ratio of gas and liquid caught in the pipe.

A semi-static method was employed by Gosline[2] to measure slip velocity. In this procedure gas was bubbled through a static column of liquid, and the slip velocity calculated from the rise in the level of the liquid in the column. This method is based on an analysis of the mean specific weight of the mixture of gas and liquid during a gas-lift operation. The mean specific weight in such an operation is dependent on the specific weights of the gas and liquid used at the conditions of the experiment as well as the relative quantities of gas and liquid present. This mean specific weight can be expressed in terms of the gas rate, the gas velocity, the specific weight of the liquid, the specific weight of the gas, and the cross-sectional area of the pipe. It can also be expressed in terms of the initial height of the liquid in the pipe, the increased height of liquid in the pipe due to injection of gas, the area of the pipe, and the specific weight of the liquid. By equating these relationships the following mathematical expression for slip velocity is derived:*

$$V_s = \frac{H + \Delta H}{D_1 \, \Delta H} \left[\frac{W_g \, R \, D_1}{2A} \left(\frac{T_2}{P_1} - \frac{T_2}{P_2} \right) - \frac{W_g}{A} \right] \quad \ldots\ldots\ldots\ldots\ldots (1)$$

This expression represents the mean slip velocity of the gas rising in a static fluid column. All of the variables in this equation can be easily determined experimentally.

The studies of Wilde and Moore[1] and of Gosline[2] provided considerable data for use in gas lift operations. Their studies covered a reasonable variety of tube sizes and liquids but did not provide a great deal of information in the range of low gas rates normally encountered in subsurface gas-oil separation equipment. The present investigation was conducted because of this lack of data. In addition to the extension of slip velocity data into the region of lower gas rates, data were obtained to better define the effects of gas and liquid properties on slip velocity.

In this investigation, the experimental techniques employed by Gosline[2] were used to determine gas slippage. The experimental determination of gas slippage was investigated in 15-ft vertical glass columns, having reasonably uniform inside diameters of two, three and four in. Auxiliary equipment was provided for the measurement of gas rates into and out of the columns and for the measurement of temperatures and pressures at the bottom and top of the columns. Gas-permeable porous discs were installed at the bottom of the columns to disperse the inlet gas. The four-in. column was installed so that it could be tilted from the vertical in order to study the effect of inclination from the vertical on gas slippage. Solid rods of various diameters were provided for insertion in the glass columns to study slip velocity in annuli. A schematic diagram of the experimental equipment described herein is shown in Fig. 1.

In the operation of the equipment, the liquid to be studied was first pumped into the column of interest. Gas was then bubbled through the liquid until it was saturated with the gas. At the start of an experiment the liquid height in the column was measured. The desired gas rate was then established and this rate was maintained constant into and out of the column. During the operation the liquid rise in the column was measured and the temperatures and pressures at the bottom and top of the column noted. Using these measured quantities, the mean slip velocity was calculated from Equation (1).

During the slip velocity measurements visual observations were made of the type and character of gas bubbles formed in the column. A description of the flow of methane through the three-in. tube filled with the heavy refined oil is typical of the phenomena observed. In this case, at low gas rates (0.09 Mcf/D) bubbles of varying size rose slowly as flattened

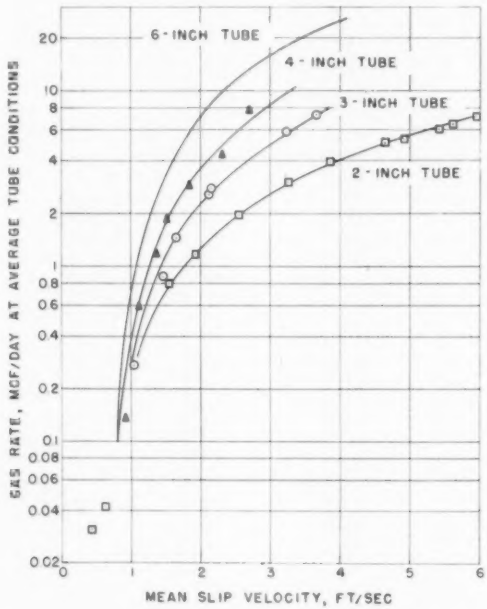

FIG. 2 — MEAN SLIP VELOCITY OF NATURAL GAS THROUGH LIGHT REFINED OIL IN VERTICAL TUBES.

Average Conditions: Gas density — 0.050 lb/cu ft; Liquid density—53.4 lb/cu ft; $\frac{\text{Liquid viscosity}}{\text{Liquid density}} = 0.536 \frac{\text{cp}}{\text{lb/cu ft}}$

*Nomenclature at the end of paper.

Table I — Properties of Liquids Used in Slip Velocity Study

Liquid	Density at 60°F, lb/cu ft	Viscosity at 80°F cp
Water	62.4	0.87
Light refined oil	53.9	33.1
Heavy refined oil	56.4	159
Light crude oil	58.5	924
Heavy crude oil	62.1	16,000

spheres. At higher gas rates (0.37 Mcf/D) some of the larger bubbles became umbrella-shaped. The umbrella spread to the diameter of the tube and developed a tail to give a bullet shaped appearance when the gas rate was increased to 1.12 Mcf/D. At still higher gas rates (around 11.15 Mcf/D) alternate slugs of gas and liquid occupied the tube. In the course of the foregoing observations, it was also estimated by a semi-quantitative material-balance technique that the mean slip velocities measured represented the slip velocity of over 99 volume per cent of the gas present. The remaining one per cent, or less, of the total gas was in the form of smaller bubbles which had no measurable slip velocity.

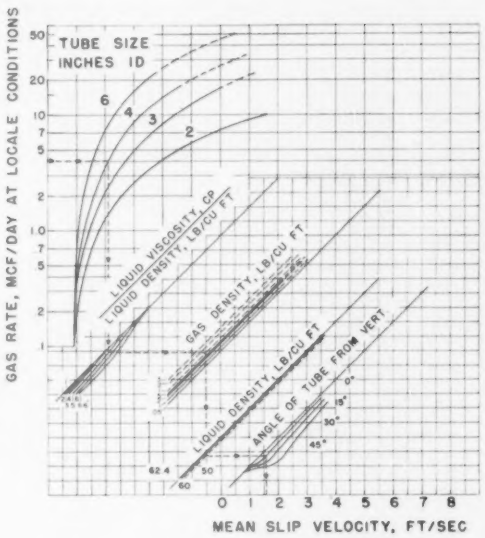

FIG. 3 — MEAN SLIP VELOCITY OF GASES THROUGH LIQUIDS.

SCOPE OF WORK

A total of 214 data points giving the rate at which gases slip through liquids was obtained. These data were determined in vertical tubes, in inclined tubes, and in vertical annuli.

Three gases were utilized in this investigation:

1. Natural gas (over 97 per cent methane)
2. Air
3. Propane (Phillips Technical Grade)

The liquids employed in conjunction with the various gases are listed together with other pertinent data in Table I.

In the course of this investigation, the following process variables were studied: gas rate, gas density, tube diameter, liquid density, liquid viscosity, gas dispersion, disc permeability, inclination of tube from the vertical, average tube temperature, and average tube pressure. The effects of all of these variables were investigated over the ranges summarized in Table II. These data are tabulated in detail in Tables III and IV.

Table II — Ranges of the Experimental Data

Variable	Range Minimum	Range Maximum
Gas rate, Mcf/D at average tube conditions	0.0187	39,366
Gas density, lb/cu ft at average tube conditions	0.0426	0.7066
Tube diameter, in.		
Open tube	2	4
Annuli on equivalent tube basis*	2.79	3.97
Liquid density, lb/cu ft at average tube conditions	53.9	62.4
Liquid viscosity to density ratio, $\frac{\text{cp}}{\text{lb/cu ft}}$ at average tube conditions	0.0103	181.9
Gas dispersion disc permeability, md	58	2,000
Inclination from vertical, degrees	0	45
Temperature at average tube conditions, °F	60	104
Pressure at average tube conditions, psia	15	83

*$D_e = \sqrt{D_o^2 - D_i^2}$

CORRELATIONS

In the correlation of the data over the operating ranges investigated, it was found that the gas rate and the tube or pipe size had the greatest effect on the gas slip velocity. The effects of such other variables as liquid viscosity, liquid density, gas density, and angle of tube from the vertical were relatively minor in comparison. The effects of temperature and pressure on the system were exhibited as changes in the physical properties of the gas and liquid used so it was not necessary to consider temperature or pressure in the correlation as specific physical properties. Gas dispersion disc permeability had no measurable effect on slip velocity over the range of permeabilities from 58 to 2,000 md, so it was not utilized in the correlation of data.

Fig. 2 presents a correlation of slip velocity with tube size and gas rate. For the data plotted all other variables were constant. An excellent correlation is shown. This graph includes, in addition to the data obtained from Table II for two, three, and four-in. tubes, a plot for a six-in. tube calculated from data obtained by Gosline.[3] Similar plots were also made relating gas rate to slip velocity using angle of inclination, gas density, liquid density and liquid viscosity-to-density ratio as correlating parameters. As in Fig. 2, all other variables except those correlated were held constant. None of these variables affected slip velocity as significantly as tube size. All of these individual plots were then combined to produce the final correlations shown in Figs. 3 and 4. In the correlation,

Table III — Open Tube Gas Slippage Experiments and Results

Liquid	Gas	Tube Size, In.	Tube Tilt From Vertical	Gas Rate Mcf/D**	Temperature °F	Average Pressure, psia	Density, lb/cu ft** Gas	Density, lb/cu ft** Liquid	Liquid Viscosity, cp**	Slip Velocity ft/sec
Water	Natural Gas*	4.0	0°	0.0818	76	16.5	0.0485	62.3	0.92	0.92
Water	Natural Gas*	4.0	0°	1.9062	82	16.4	0.0475	62.2	0.84	1.44
Water	Natural Gas*	4.0	0°	5.1112	82	16.4	0.0475	62.2	0.84	2.29
Water	Natural Gas*	4.0	0°	9.4335	82	16.9	0.0490	62.2	0.84	2.96
Water	Natural Gas*	4.0	0°	12.6029	76	24.7	0.0726	62.3	0.92	4.08
Water	Natural Gas*	4.0	20.5°	0.0298	88	15.6	0.0449	62.2	0.78	0.79
Water	Natural Gas*	4.0	20.5°	0.5518	90	16.2	0.0465	62.2	0.76	1.58
Water	Natural Gas*	4.0	20.5°	2.5507	90	16.0	0.0460	62.1	0.76	2.06
Water	Natural Gas*	4.0	20.5°	3.7548	91	16.8	0.0480	62.1	0.75	2.52
Water	Natural Gas*	4.0	20.5°	6.5591	92	20.8	0.0595	62.1	0.74	3.00
Water	Natural Gas*	4.0	35.5°	0.0377	91	16.2	0.0463	62.1	0.75	0.92
Water	Natural Gas*	4.0	35.5°	0.5080	92	15.7	0.0449	62.1	0.74	1.61
Water	Natural Gas*	4.0	35.5°	1.9125	92	16.1	0.0459	62.1	0.74	2.02
Water	Natural Gas*	4.0	35.5°	3.2537	93	16.6	0.0474	62.1	0.73	2.35
Water	Natural Gas*	4.0	35.5°	6.3000	93	20.2	0.0576	62.1	0.73	3.03
Water	Natural Gas*	4.0	45°	0.0222	93	15.3	0.0435	62.1	0.73	1.10
Water	Natural Gas*	4.0	45°	0.6668	81	15.8	0.0460	62.2	0.86	2.18
Water	Natural Gas*	4.0	45°	1.6104	81	15.4	0.0448	62.2	0.86	2.26
Water	Natural Gas*	4.0	45°	2.1485	81	15.5	0.0452	62.2	0.86	2.38
Water	Natural Gas*	4.0	45°	2.9507	81	15.8	0.0460	62.2	0.86	2.55
Water	Natural Gas*	4.0	45°	5.8192	82	18.6	0.0540	62.2	0.85	3.20
Water	Natural Gas*	4.0	45°	7.1392	82	21.2	0.0616	62.2	0.85	3.33
Water	Natural Gas*	4.0	45°	0.0173	74	16.3	0.0430	62.3	0.95	0.67
Water	Natural Gas*	3.0	0°	0.0412	90	15.8	0.0453	62.2	0.76	0.90
Water	Natural Gas*	3.0	0°	0.0429	93	15.7	0.0449	62.1	0.73	0.90
Water	Natural Gas*	3.0	0°	0.0704	94	15.7	0.0448	62.1	0.72	0.94
Water	Natural Gas*	3.0	0°	0.1015	90	15.8	0.0453	62.2	0.76	0.96
Water	Natural Gas*	3.0	0°	0.1553	74	17.2	0.0508	62.3	0.95	0.94
Water	Natural Gas*	3.0	0°	0.2055	90	15.8	0.0454	62.2	0.76	1.05
Water	Natural Gas*	3.0	0°	0.2624	94	15.8	0.0451	62.1	0.72	1.09
Water	Natural Gas*	3.0	0°	0.4051	94	16.9	0.0482	62.1	0.72	0.60
Water	Natural Gas*	3.0	0°	0.4155	90	16.5	0.0472	62.2	0.76	0.80
Water	Natural Gas*	3.0	0°	1.2207	91	16.3	0.0465	62.1	0.75	1.57
Water	Natural Gas*	3.0	0°	1.7953	97	15.8	0.0449	62.1	0.70	1.79
Water	Natural Gas*	3.0	0°	2.3237	91	16.3	0.0467	62.1	0.75	1.98
Water	Natural Gas*	3.0	0°	2.8945	97	16.1	0.0457	62.1	0.70	2.17
Water	Natural Gas*	3.0	0°	3.1379	97	16.2	0.0459	62.1	0.70	2 22
Water	Natural Gas*	3.0	0°	4.0147	91	16.3	0.0467	62.1	0.75	2.53
Water	Natural Gas*	3.0	0°	16.0050	74	23.6	0.0698	62.3	0.95	6.25
Water	Natural Gas*	3.0	0°	0.0130	94	83.2	0.2368	62.1	0.72	0 90
Water	Natural Gas*	2.0	0°	0.0133	103	45.8	0.1284	62.0	0.65	0.57
Water	Natural Gas*	2.0	0°	0.0279	102	32.8	0.0922	62.0	0.66	0.88
Water	Natural Gas*	2.0	0°	0.0320	70	15.6	0.0465	62.4	1.02	0.88
Water	Natural Gas*	2.0	0°	0.0796	103	45.3	0.1270	62.0	0.65	0.70
Water	Natural Gas*	2.0	0°	0.1192	102	34.3	0.0964	62.0	0.66	1.01
Water	Natural Gas*	2.0	0°	0.1970	91	63.4	0.1816	62.1	0.75	0.93
Water	Natural Gas*	2.0	0°	0.2692	102	33.8	0.0950	62.0	0.66	1.02
Water	Natural Gas*	2.0	0°	0.3785	103	46.1	0.1292	62.0	0.65	1.09
Water	Natural Gas*	2.0	0°	0.4696	102	34.4	0.0966	62.0	0.66	1.14
Water	Natural Gas*	2.0	0°	0.5457	96	83.2	0.2359	62.1	0.70	1.16
Water	Natural Gas*	2.0	0°	0.5554	72	15.6	0.0462	62.3	0 98	1.46
Water	Natural Gas*	2.0	0°	0.5934	94	63.8	0.1817	62.1	0.72	1.22
Water	Natural Gas*	2.0	0°	0.7688	73	15.6	0.0463	62.3	0.96	1.29
Water	Natural Gas*	2.0	0°	0.8674	103	45.8	0.1284	62.0	0.65	1.45
Water	Natural Gas*	2.0	0°	0.9397	97	83.8	0.2374	62.1	0.70	1.44
Water	Natural Gas*	2.0	0°	0.9804	102	33.8	0.0950	62.0	0.66	1.55
Water	Natural Gas*	2.0	0°	1.1018	94	63.9	0.1820	62.1	0.72	1.56
Water	Natural Gas*	2.0	0°	1.2339	97	83.2	0.2357	62.1	0.70	1.61
Water	Natural Gas*	2.0	0°	1.4322	94	63.7	0.1814	62.1	0.72	1.77
Water	Natural Gas*	2.0	0°	1.4444	102	34.6	0.0972	62.0	0.66	1.83
Water	Natural Gas*	2.0	0°	1.7486	74	15.6	0.0462	62.3	0.95	2.17
Water	Natural Gas*	2 0	0°	1.8811	90	46.4	0.1332	62.2	0.76	2.30
Water	Natural Gas*	2.0	0°	4.4634	75	15.1	0 0446	62.3	0.94	3.72
Water	Natural Gas*	2.0	0°	0.1361	90	16.0	0 0458	53.2	24	0.92
Lt. Ref. Oil	Nat. Gas*	4.0	0°	0.5952	80	16.0	0.0466	53.4	33	1.12
Lt. Ref. Oil	Nat. Gas*	4.0	0°	1.1827	89	19.0	0.0553	53.4	33	1.39
Lt. Ref. Oil	Nat. Gas*	4.0	0°	1.8452	80	16.4	0.0479	53.4	33	1.52
Lt. Ref. Oil	Nat. Gas*	4.0	0°	2.8660	82	16.9	0.0492	53.4	32	1 84
Lt. Ref. Oil	Nat. Gas*	4.0	0°	3.7503	83	17.4	0.0505	53.4	30	2.05
Lt. Ref. Oil	Nat. Gas*	4.0	0°	4.3333	83	17.9	0.0520	53.4	30	2.31
Lt. Ref. Oil	Nat. Gas*	4.0	0°	7.8713	80	19.2	0.0562	53.4	33	2.70
Lt. Ref. Oil	Nat. Gas*	4.0	0°	0.2785	92	16.0	0.0456	53.2	22	1.05
Lt. Ref. Oil	Nat. Gas*	3.0	0°	0.5187	62	16.5	0.0498	53.8	86	1.15
Lt. Ref. Oil	Nat. Gas*	3.0	0°	0.8712	92	16.9	0.0483	53.2	22	1.49
Lt. Ref. Oil	Nat. Gas*	3.0	0°	1.0162	63	17.5	0.0528	53.8	81	1.47
Lt. Ref. Oil	Nat. Gas*	3.0	0°	1.2975	63	18.6	0.0562	53.8	81	1.63

Table III — (Continued)

Liquid	Gas	Tube Size, In.	Tube Tilt From Vertical	Gas Rate Mcf/D**	Temperature °F	Average Pressure, psia	Density, lb/cu ft** Gas	Density, lb/cu ft** Liquid	Liquid Viscosity, cp**	Slip Velocity ft/sec
Lt. Ref. Oil	Nat. Gas*	3.0	0°	1.4229	92	16.0	0.0456	53.2	22	1.67
Lt. Ref. Oil	Nat. Gas*	3.0	0°	1.5993	64	20.3	0.0611	53.8	78	1.75
Lt. Ref. Oil	Nat. Gas*	3.0	0°	2.5152	92	16.1	0.0461	53.2	22	2.12
Lt. Ref. Oil	Nat. Gas*	3.0	0°	2.7167	92	16.5	0.0471	53.2	22	2.17
Lt. Ref. Oil	Nat. Gas*	3.0	0°	5.8028	76	17.6	0.0518	53.5	41	3.22
Lt. Ref. Oil	Nat. Gas*	3.0	0°	7.2325	76	19.0	0.0558	53.5	41	3.67
Lt. Ref. Oil	Nat. Gas*	2.0	0°	0.0310	78	16.8	0.0468	53.5	38	0.43
Lt. Ref. Oil	Nat. Gas*	2.0	0°	0.0419	82	16.0	0.0466	53.4	32	0.62
Lt. Ref. Oil	Nat. Gas*	2.0	0°	0.7981	82	16.7	0.0485	53.4	32	1.56
Lt. Ref. Oil	Nat. Gas*	2.0	0°	1.1799	83	16.0	0.0465	53.4	30	1.91
Lt. Ref. Oil	Nat. Gas*	2.0	0°	1.9175	83	16.0	0.0465	53.4	30	2.56
Lt. Ref. Oil	Nat. Gas*	2.0	0°	2.9940	100	15.1	0.0426	53.0	20	3.28
Lt. Ref. Oil	Nat. Gas*	2.0	0°	3.9510	100	15.5	0.0437	53.0	21	3.87
Lt. Ref. Oil	Nat. Gas*	2.0	0°	4.9689	80	17.0	0.0498	53.4	33	4.66
Lt. Ref. Oil	Nat. Gas*	2.0	0°	5.3572	78	16.4	0.0479	53.5	38	4.92
Lt. Ref. Oil	Nat. Gas*	2.0	0°	6.1310	100	16.4	0.0469	53.0	21	5.36
Lt. Ref. Oil	Nat. Gas*	2.0	0°	6.5650	78	17.3	0.0508	53.5	38	5.61
Lt. Ref. Oil	Nat. Gas*	2.0	0°	7.1776	79	17.6	0.0514	53.5	38	5.97
Lt. Ref. Oil	Nat. Gas*	2.0	0°	7.8880	100	17.7	0.0499	53.0	21	6.32
Lt. Ref. Oil	Nat. Gas*	2.0	0°	10.9190	100	22.4	0.0631	53.0	21	8.12
Lt. Ref. Oil	Nat. Gas*	2.0	0°	29.8850	95	19.8	0.0563	53.1	23	19.66
Lt. Ref. Oil	Nat. Gas*	2.0	0°	39.3660	96	24.6	0.0698	53.1	22	24.02
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	0.1513	70	16.1	0.0478	56.2	257	0.74
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	0.1588	79	16.0	0.0469	56 0	180	0.52
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	0.4421	70	16.1	0.0512	56.2	257	0.58
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	1.7420	70	16.1	0.0494	56.2	257	1.49
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	1.8934	80	16.1	0.0470	55.9	159	1.55
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	2.2776	70	16.2	0.0481	56.2	249	1.58
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	2.8250	80	16.1	0.0471	55.9	159	1.90
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	5.9005	70	17.9	0.0533	56.2	249	2.56
Hvy. Ref. Oil	Nat. Gas*	4.0	0°	7.6235	69	19.4	0.0578	56.2	249	2.93
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	0.0335	73	16.0	0.0474	56.1	217	0.43
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	0.1553	73	16.0	0.0474	56.1	217	0.62
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	0.4194	69	16.2	0.0482	56 2	249	0.82
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	0.4385	69	17.8	0.0532	56.2	249	1.38
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	1.3199	72	15.9	0.0470	56.1	222	1.14
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	1.6786	69	20.5	0.0612	56.2	249	1.66
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	2.3346	72	15.9	0.0470	56.1	222	1.64
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	2.9222	73	15.9	0.0471	56.1	217	2.01
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	5.2590	73	17.1	0.0507	56.1	217	3.07
Hvy. Ref. Oil	Nat. Gas*	3.0	0°	6.8819	67	17.3	0.0518	56.2	281	3.58
Hvy. Ref. Oil	Nat. Gas*	2.0	0°	0.0446	68	16.0	0.0479	56.2	263	0.61
Hvy. Ref. Oil	Nat. Gas*	2.0	0°	0.0837	68	16.0	0.0479	56.2	263	0.62
Hvy. Ref. Oil	Nat. Gas*	2.0	0°	0.3163	69	16.0	0.0478	56.2	249	0.85
Hvy. Ref. Oil	Nat. Gas*	2.0	0°	1.4912	69	16.0	0.0478	56.2	249	1.96
Hvy. Ref. Oil	Nat. Gas*	2.0	0°	4.5597	76	15.8	0.0465	56.0	190	4.68
Hvy. Ref. Oil	Nat. Gas*	2.0	0°	6.8953	76	17.6	0.0517	56.0	190	6.38
Lt. Crude Oil	Nat. Gas*	4.0	0°	0.0255	89	16.2	0.0464	57.8	384	0.17
Lt. Crude Oil	Nat. Gas*	4.0	0°	0.2077	89	16.2	0.0466	57.8	384	0.33
Lt. Crude Oil	Nat. Gas*	4.0	0°	1.0964	89	18.4	0.0528	57.8	384	0.88
Lt. Crude Oil	Nat. Gas*	4.0	0°	2.2587	89	16.2	0.0464	57.8	384	1.01
Lt. Crude Oil	Nat. Gas*	4.0	0°	3.3586	89	16.4	0.0470	57.8	384	1.30
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	0.0437	86	16.1	0.0465	61.5	8,860	0.20
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	0.4039	89	16.1	0.0462	61.5	7,070	0.49
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	0.9201	90	16.1	0.0462	61.4	6,680	0.69
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	1.4600	91	16.1	0.0461	61.4	6,280	0.85
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	1.8404	91	16.1	0.0461	61.4	6,280	0.96
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	2.0586	92	16.1	0.0460	61.4	5,690	1.03
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	4.8847	83	17.6	0.0511	61.6	11,300	1.78
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	8.6519	86	22.6	0.0652	61.5	8,860	2.81
Hvy. Cr. Oil	Nat. Gas*	4.0	0°	9.8006	87	27.2	0.0804	61.5	8,460	3.18
Water	Air	4.0	0°	0.3122	71	16.6	0.0844	62.3	0.99	0.83
Water	Air	4.0	0°	3.6123	77	17.7	0.0890	62.3	0.91	1.62
Water	Air	4.0	0°	4.5410	77	18.9	0.0950	62.3	0.91	1.86
Lt. Ref. Oil	Air	4.0	0°	0.1585	86	15.9	0.0785	53.3	27	0.57
Lt. Ref. Oil	Air	4.0	0°	1.7225	87	16.0	0.0789	53.3	25	1.50
Lt. Ref. Oil	Air	4.0	0°	2.6763	83	16.5	0.0820	53.4	30	1.68
Hvy. Ref. Oil	Air	4.0	0°	0.0295	73	16.2	0.0819	56.1	217	0.68
Hvy. Ref. Oil	Air	4.0	0°	0.1380	76	16.3	0.0820	56.0	190	0.55
Hvy. Ref. Oil	Air	4.0	0°	1.2096	76	16.3	0.0820	56.0	190	1.26
Hvy. Ref. Oil	Air	4.0	0°	1.6820	76	16.4	0.0827	56.0	190	1.29
Hvy. Ref. Oil	Air	4.0	0°	3.8836	79	17.7	0.0885	56.0	180	2.11
Hvy. Ref. Oil	Air	4.0	0°	6.3202	80	21.1	0.1054	55.9	159	2.57
Water	Propane	4.0	0°	0.0756	78	16.6	0.1268	62.3	0.89	0.84
Water	Propane	4.0	0°	2.7218	79	17.9	0.1365	62.3	0.88	1.51
Water	Propane	4.0	0°	3.4777	80	18.8	0.1431	62.2	0.87	1.65

Table III — (Continued)

Liquid	Gas	Tube Size, In.	Tube Tilt From Vertical	Gas Rate Mcf/D**	Temperature °F	Average Pressure, psia	Density, lb/cu ft** Gas	Density, lb/cu ft** Liquid	Liquid Viscosity, cp**	Slip Velocity ft/sec
Water	Propane	4.0	0°	3.6331	79	18.8	0.1434	62.3	0.88	1.75
Water	Propane	2.0	0°	0.0080	103	84.9	0.6741	62.0	0.65	0.55
Water	Propane	2.0	0°	0.0585	89	83.6	0.6828	62.2	0.77	0.57
Water	Propane	2.0	0°	0.0702	103	82.8	0.6575	62.0	0.65	0.52
Water	Propane	2.0	0°	0.1968	89	83.6	0.6878	62.2	0.77	0.81
Water	Propane	2.0	0°	0.2973	103	83.8	0.6654	62.0	0.65	0.86
Water	Propane	2.0	0°	0.3249	90	83.6	0.6872	62.2	0.76	0.88
Water	Propane	2.0	0°	0.3774	90	83.3	0.6847	62.2	0.76	0.87
Water	Propane	2.0	0°	0.4292	103	83.1	0.6598	62.0	0.65	0.94
Water	Propane	2.0	0°	0.5212	103	83.1	0.6598	62.0	0.65	1.05
Water	Propane	2.0	0°	0.5355	103	82.7	0.6567	62.0	0.65	1.04
Lt. Ref. Oil	Propane	4.0	0°	0.3319	88	16.3	0.1221	53.3	24	0.50
Lt. Ref. Oil	Propane	4.0	0°	0.6878	75	16.0	0.1226	53.6	45	1.04
Lt. Ref. Oil	Propane	4.0	0°	1.3167	75	16.0	0.1233	53.6	45	1.12
Lt. Ref. Oil	Propane	4.0	0°	4.5151	75	19.1	0.1470	53.6	45	2.02
Hvy. Ref. Oil	Propane	4.0	0°	0.0303	79	16.1	0.1236	56.0	180	0.64
Hvy. Ref. Oil	Propane	4.0	0°	0.1478	83	16.2	0.1228	55.9	141	0.85
Hvy. Ref. Oil	Propane	4.0	0°	1.3167	85	16.3	0.1231	55.8	128	1.48
Hvy. Ref. Oil	Propane	4.0	0°	1.4607	85	16.4	0.1238	55.8	128	1.24
Hvy. Ref. Oil	Propane	4.0	0°	3.4625	86	17.7	0.1334	55.8	125	1.87
Hvy. Ref. Oil	Propane	4.0	0°	5.5106	86	21.7	0.1635	55.8	125	2.41
Hvy. Ref. Oil	Propane	2.0	0°	0.1997	96	82.7	0.1997	55.6	42	0.57
Hvy. Ref. Oil	Propane	2.0	0°	0.3814	96	83.1	0.3814	55.6	42	0.78
Hvy. Ref. Oil	Propane	2.0	0°	0.4461	96	83.1	0.4461	55.6	42	0.85
Hvy. Ref. Oil	Propane	2.0	0°	0.5121	96	83.1	0.5121	55.6	42	0.91

*Over 97% Methane.
**Measured at conditions of temperature and pressure specified in the table.

Table IV — Annuli Gas Slippage Experiments and Results

Liquid	Gas	Annuli Dimensions* OD, In.	Annuli Dimensions* ID, In.	Equivalent Open Tube Size, In.	Tube Tilt From Vertical	Gas Rate Mcf/D***	Temperature, °F	Pressure, psia	Density, lb/cu ft*** Gas	Density, lb/cu ft*** Liquid	Liquid Viscosity cp***	Slip Velocity ft/sec
Water	Natural Gas**	4.0	0.50	3.9	0°	0.0279	91	16.1	0.0461	62.1	0.75	0.78
Water	Natural Gas**	4.0	0.50	3.9	0°	0.2551	92	16.2	0.0464	62.1	0.74	1.02
Water	Natural Gas**	4.0	0.50	3.9	0°	0.8197	93	17.1	0.0488	62.1	0.73	1.24
Water	Natural Gas**	4.0	0.50	3.9	0°	1.7861	103	16.5	0.0461	62.0	0.65	1.40
Water	Natural Gas**	4.0	0.50	3.9	0°	2.2252	103	16.6	0.0464	62.0	0.65	1.56
Water	Natural Gas**	4.0	0.50	3.9	0°	2.6382	104	16.7	0.0468	62.0	0.64	1.67
Water	Natural Gas**	4.0	0.50	3.9	0°	2.6561	93	16.5	0.0472	62.1	0.73	1.78
Water	Natural Gas**	4.0	1.1	3.8	0°	0.0425	90	15.6	0.0447	62.2	0.76	0.94
Water	Natural Gas**	4.0	1.1	3.8	0°	0.1150	90	15.6	0.0447	62.2	0.76	1.01
Water	Natural Gas**	4.0	1.1	3.8	0°	0.3302	90	15.7	0.0450	62.2	0.76	1.08
Water	Natural Gas**	4.0	1.1	3.8	0°	1.1327	90	15.6	0.0447	62.2	0.76	1.33
Water	Natural Gas**	4.0	1.1	3.8	0°	1.7875	90	15.7	0.0450	62.2	0.76	1.57
Water	Natural Gas**	4.0	1.1	3.8	0°	2.4034	90	16.0	0.0458	62.2	0.76	1.75
Water	Natural Gas**	4.0	1.1	3.8	0°	2.8750	90	16.0	0.0458	62.2	0.76	1.92
Water	Natural Gas**	4.0	1.1	3.8	0°	4.4800	90	16.9	0.0486	62.2	0.76	2.30
Water	Natural Gas**	4.0	1.1	3.8	0°	6.5864	90	19.0	0.0544	62.2	0.76	2.73
Water	Natural Gas**	4.0	1.1	3.8	0°	7.9794	90	21.6	0.0620	62.2	0.76	2.99
Water	Natural Gas**	4.0	2.0	3.5	0°	0.0280	99	16.3	0.0460	62.0	0.68	1.08
Water	Natural Gas**	4.0	2.0	3.5	0°	0.0289	95	16.4	0.0467	62.1	0.71	0.92
Water	Natural Gas**	4.0	2.0	3.5	0°	0.1756	99	16.4	0.0464	62.0	0.68	1.06
Water	Natural Gas**	4.0	2.0	3.5	0°	0.3460	96	16.6	0.0472	62.1	0.70	0.99
Water	Natural Gas**	4.0	2.0	3.5	0°	0.6135	101	16.9	0.0476	62.0	0.67	1.21
Water	Natural Gas**	4.0	2.0	3.5	0°	0.7529	97	17.3	0.0490	62.1	0.70	1.30
Water	Natural Gas**	4.0	2.0	3.5	0°	0.8827	102	16.4	0.0461	62.0	0.66	1.28
Water	Natural Gas**	4.0	2.0	3.5	0°	1.5212	97	16.5	0.0468	62.1	0.70	1.68
Water	Natural Gas**	4.0	2.0	3.5	0°	1.5889	101	16.6	0.0466	62.0	0.67	1.62
Water	Natural Gas**	4.0	2.0	3.5	0°	2.1307	97	16.7	0.0472	62.1	0.70	1.89
Water	Natural Gas**	4.0	2.0	3.5	0°	2.1434	102	16.7	0.0468	62.0	0.66	1.84
Water	Natural Gas**	4.0	2.0	3.5	0°	2.7911	102	16.8	0.0473	62.0	0.66	2.00
Water	Natural Gas**	4.0	2.0	3.5	0°	2.9434	98	16.9	0.0477	62.0	0.69	2.15
Water	Natural Gas**	3.0	1.1	2.8	0°	0.5422	87	16.1	0.0465	62.2	0.79	1.42
Water	Natural Gas**	3.0	1.1	2.8	0°	1.0601	85	16.3	0.0470	62.2	0.81	1.58
Water	Natural Gas**	3.0	1.1	2.8	0°	1.4839	85	16.3	0.0470	62.2	0.81	1.82
Water	Natural Gas**	3.0	1.1	2.8	0°	1.5847	90	16.2	0.0465	62.2	0.76	1.75
Water	Natural Gas**	3.0	1.1	2.8	0°	1.9768	86	16.6	0.0480	62.2	0.80	2.00
Water	Natural Gas**	3.0	1.1	2.8	0°	2.0670	89	16.3	0.0469	62.2	0.77	1.94
Water	Natural Gas**	3.0	1.1	2.8	0°	2.8481	84	16.7	0.0480	62.2	0.82	2.32

*Equivalent Open Tube Size = $\sqrt{(OD)^2 - (ID)^2}$
**Over 97% Methane
***Measured at conditions of temperature and pressure specified in the table.

most of the data were found easily resolvable to correlations of the type shown in Fig. 2, so no mathematical analysis of the data was attempted. Extrapolated portions of data are represented by dotted lines.

Fig. 4 is an expansion of that portion of Fig. 3 used to determine the slip velocity in the range below 7.5 ft/sec. Consequently, the effects of the different variables in this region, corresponding to low gas rates, may be presented in greater detail. The emphasis on this region of the chart by means of the expansion is reasonable since 208 of the 214 experimental data points used for correlating purposes are included in Fig. 4.

Fig. 3 presents slip velocity values as high as 24.0 ft/sec. However, these high values are based on a limited amount of experimental evidence. This chart is useful primarily for systems having relatively high slip velocities and to obtain rough values of systems having low slip velocities. In both Figs. 3 and 4, the data for the six-in. columns were taken from the investigation reported by Gosline.[3]

Temperature and pressure changes affect the measured physical properties of gases and liquids. As presented in this paper, the slip velocity of gases through liquids has been correlated with the various parameters at the temperature and pressure of measurement. Since the effects of temperature and pressure on slip velocity are included in the changes in the physical properties exhibited by the gases and liquids used, the correlations in Figs. 3 and 4 are deemed usable at temperatures and pressures outside the ranges given in Table II, provided that the physical properties of the gas and liquid involved at the temperatures and pressures in question fall within the limits covered for these variables in this investigation. From the data in Table IV it was found that slip

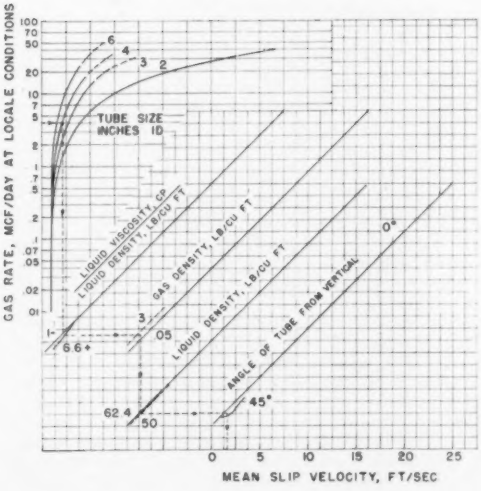

FIG. 4 — MEAN SLIP VELOCITY OF GASES THROUGH LIQUIDS.

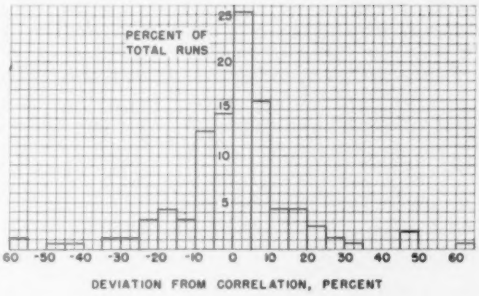

FIG. 5 — DEVIATION OF DATA FROM THE CORRELATION.

velocities in annuli were related to slip velocities in tubes by the tube equivalent diameter. This diameter is defined as the diameter of an open tube of cross-sectional area equal to the annulus cross-sectional area, or

$$D_a = \sqrt{D_o^2 - D_i^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Slip velocities in annuli can thus be obtained by using the correlation in Figs. 3 and 4 along with the relationship shown in Equation (2). The equivalent tube diameter is calculated from Equation (2) and this tube diameter is then used in Figs. 3 and 4 for the prediction of slip velocity.

The overall accuracy of the correlation representing the experimental data from this investigation is demonstrated by a value of 9.2 per cent for the average numerical deviation between measured slip velocities and those predicted from the correlation obtained from these same measured values. The average algebraic deviation between measured and predicted slip velocities of +0.31 per cent indicates that the correlation is a reasonable representation of the data obtained. A further evaluation of the correlation accuracy is demonstrated by the error distribution chart presented in Fig. 5. This chart shows that 71.2 per cent of the measured slip velocities fall within a ±10 per cent deviation from values predicted by the chart and that the errors fall approximately on a normal distribution curve.

APPLICATIONS

In the use of the correlation presented in Figs. 3 and 4, it should be emphasized that the numerical values of the variables used in the correlation must correspond to the conditions actually existing at the locale where the slip velocity is to be be determined. Where the properties of the gas and oil of interest are known only at well-head conditions, these properties must be corrected to those existing at bottom-hole conditions in order to predict slip velocity at the bottom of a well.

The procedure which should be used to determine the mean slip velocity from the correlation in Figs. 3 and 4 is illustrated

by the following example. Let us assume that calculated conditions, at some depth, x, in a well, result in the following values:

Gas rate = 4 Mcf/D under conditions at level x
Tubing size = 4 in.
Viscosity-density ratio $\left(\frac{\text{cp}}{\text{lb/cu ft}}\right) = 5$
Gas density = 1 lb/cu ft
Liquid density = 50 lb/cu ft
Inclination of tube from vertical = 15°

The determination of the mean slip velocity from Fig. 3 using the parameters given above can be accomplished by following the directionally indicated dashed line on Fig. 3. This produces a mean slip velocity of 1.5 ft/sec. By following the same procedure on Fig. 4 a somewhat more accurate slip velocity of 1.58 ft/sec is obtained.

ACKNOWLEDGMENTS

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NOMENCLATURE

A = Cross sectional area of the tube, sq ft
cp = Viscosity in centipoise
D_e = Equivalent tube diameter, in.
D_i = Inside diameter of annulus, in.
D_l = Density of liquid, lb/cu ft
D_o = Outside diameter of annulus, in.
H = Static liquid level, ft
$\triangle H$ = Increment in liquid level due to the presence of flowing gas, ft
P = Pressure in the tube, psia
R = Perfect gas law constant, $\frac{10.72}{\text{molecular wt}}$
T = Temperature in the tube, °R
V_s = Average slip velocity, ft/sec
W_g = Mass rate of gas flow, lb/sec
Subscript 1 = Bottom of tube
Subscript 2 = Top of tube

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The Drift of Things

. . . as followed by **EDWARD H. ROBIE**
Secretary AIME

New Name for the Institute?

Should the name of our Institute be changed? Perhaps one should say, should it *again* be changed, for until 1919 the name was the American Institute of Mining Engineers. When the American Institute of Metals joined our ranks we became the American Institute of Mining and Metallurgical Engineers. To make it a full mouthful, and strictly legal, one should add the word "Incorporated."

At the June meeting of the Board of Directors it was suggested that this name was not a particularly happy one, especially so far as members of the Petroleum Branch, comprising a quarter of our membership, were concerned. It did not seem particularly appropriate as the name for the professional society for petroleum engineers. Apart from the petroleum group, the present name is felt by some not to be sufficiently comprehensive, most geologists and many metallurgists and fuel technologists, for instance, are not engineers. They could never qualify as registered professional engineers under the licensing laws and yet they are valued and fully qualified members of the AIME.

The directors, at the June meeting, thought the idea of a change in name should be presented to the membership for discussion, and suggested this column as the avenue of approach.

Nine years ago Dean Steidle, of Penn State, recommended among other things that the name of the Institute be changed to "American Institute of Mineral Technologists and Engineers." In an editorial in *Mining and Metallurgy* in January, 1944, objection was offered to this name but "American Institute of Mineral Engineers" was suggested. A special committee appointed by the Board to review Dean Steidle's suggestions (W. B. Heroy was chairman) suggested that if the AIME were starting from scratch, the American Institute of Mineral Engineers might be a preferred name. It was not thought that the change suggested by Dean Steidle was one of major importance, and the comment was made that "the present name has gained prestige through many years and is cherished by our membership. An important element of 'good will' is attached to it and some of this would be unquestionably sacrified by any change."

In *Mining and Metallurgy* for February, 1945, Oliver C. Ralston went into the derivation of the terms mineralogy and metallurgy, and pointed out that both Mining and Metallurgical means "digging," etymologically. He went on to show with tongue in cheek that if we want a short and all-inclusive name it should be American Institute of Geourgists, or, for euphony, Geolurgists. Oliver's brilliant development seems to have been received with speechless wonder!

Should a decision ever be made to change the name, we think most members will agree that the American Institute of Mineral Engineers is to be preferred over anything yet suggested. "Mineral" has become, through usage, a much broader term than is indicated in the dictionary. Webster states that a mineral, in the true sense, must be inorganic, but Murray's Oxford English Dictionary seems more liberal, defining "mineral" as any substance which is obtained by mining; a product of the bowels of the earth; and "mineral oil" as any oil of mineral origin, as petroleum or shale oil. Certainly "the mineral industry" is ordinarily taken to include those activities based upon processing all the metallic and nonmetallic ores and deposits found in the ground, including the fuels. One advantage of this title is that the familiar abbreviation, "AIME" need not be changed.

But if the petroleum engineers are the ones to be chiefly considered in revising the name of the Institute, it is by no means certain that they would feel they are much more adequately recognized in a group of Mineral Engineers than in a society of Mining and Metallurgical Engineers. And then there remain, of course, the considerable number of professional members of the Institute who are not engineers at all.

Comment from readers is invited.

Labors of Love

Few members of the Institute ever stop to think of the time, thought, and money that is given freely and generously by hundreds of members to their professional society. A good part of the year of the president is devoted to traveling about the country for the society, to attending meetings, and to reviewing matters on which his counsel is needed. Most of the directors, particularly those who are able to come to frequent meetings, also take their jobs seriously. Branch, Division, and Local Section Officers, particularly chairmen and secretaries, find that many hours a month are required, which usually means that much less leisure time at home. Several hundred members serve on Institute committees, which may require scarcely any time or may require a day's work a month. Such committees as the Admissions Committee and the various Technical Publications committees are among the more active and hard-working groups. Many who are not on any committee still find they are called on for work. Such, for instance, are those especially skilled in specific fields who are asked to review critically technical papers submitted for the *Transactions*.

It is true that most of those who thus contribute to the work of the Institute benefit themselves by so doing, by widening their knowledge and their circle of friends and acquaintances in the profession, but for most this is a byproduct of their work and not the reason for their acceptance of such professional responsibility. Many of our workers are at or near the top in their companies, so added recognition from Institute work means little to them.

Undoubtedly no living member of the Institute has given more of his time to its affairs, or has been a more diligent, able, and devoted a guardian of its material well-being, and supporter of its traditional purposes and tenets, than Erle V. Daveler, who retired from the board last February after 23 full years of service as a director. For nine years he was vice-president. He served as chairman of both the Executive and Finance Committees of the Institute, and is still chairman of its Committee on Investments. Before coming to New York he served on professional committees and contributed to the Transactions.

Such men as Erle Daveler, and conspicuously he, have brought the AIME to its present stature.

At the suggestion of the board, President Haider recently transmitted to him a letter of appreciation. In replying he said, "I have always considered it a deep privilege to serve the Institute, and through my association with it there have resulted friendships with the finest group of men I know of in any organization, who all unselfishly have served it." ★ ★ ★

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Election for 1953 Branch Chairman Being Conducted

Members are now voting by letter ballot on Claude R. Hocott and Paul Weaver for the highest Petroleum Branch office. Other officers on the Nominating Committee slate were elected Aug. 15.

For the first time in a number of years, the Petroleum Branch is conducting an election between two nominees for the office of Branch Chairman for 1953. A group of AIME members nominated Paul Weaver of Gulf Oil Corp. in Houston for the chairmanship, and this necessitates an election between Weaver and Claude R. Hocott of Humble Oil and Refining Co. in Houston, who was nominated by the Branch Nominating Committee. The nomination of Weaver was made in accordance with the Branch Bylaws, which specify that the official slate of the Nominating Committee will be published in the June issue of JOURNAL OF PETROLEUM TECHNOLOGY and other nominations for any position may be submitted by ten members until August 15. When other nominations are not made by August 15 the Nominating Committee's slate will be declared elected.

The Branch Bylaws specify that such an election as required in this case will be conducted by letter ballot, and in compliance with this provision, a ballot was mailed to all Petroleum Branch members in the United States, Canada and Mexico on Sept. 8. The deadline for returning the ballot is Sept. 27.

By the absence of other nominations, other officers on the Nominating Committee slate were elected on Aug. 15. These are John P. Hammond, Amerada Petroleum Corp., Tulsa; and Basil P. Kantzer, Union Oil Co., Los Angeles, who will serve as Vice-Chairmen during 1953. Thomas A. Atkinson, General Petroleum Corp., Casper; and Roland P. Gouldy, Hull-Silk Repressuring Association, Wichita Falls, were elected for three-year terms on the Executive Committee from February, 1953 to February, 1956.

Incumbent Chairman Paul R. Turnbull appointed a Tally Committee of D. V. Carter, Magnolia Petroleum Co., Sam N. DeWitt, Century Corp., and A. S. Rhea, all of Dallas. This committee will count the ballots on Sept. 29 and the results will be announced at the Welcoming Luncheon in Houston on Oct. 1 and in the October TECHNOLOGY.

The nomination of Paul Weaver was made by some of his associates as a tribute to him before his anticipated retirement from business life within the next few years. He was born in 1888 and reared in Kentucky, then graduated with a BS from Columbia University in 1908. For a number of years he was engaged in geological work for the U. S. Survey and private companies, then from 1915 to 1926 he served as geologist and chief geologist for two oil companies in Mexico. From 1926 to 1951 he was geophysicist and chief geophysicist for the Houston Division of Gulf Oil Corp. In 1951 he became technical assistant to the vice-president of the Gulf Houston Division, and retains the position at the present time.

Claude R. Hocott, the other nominee, was born in 1909 and reared in Arkansas. He was graduated from the University of Texas with a BS in chemical engineering in 1933, then with an MS in 1934 and a PhD in 1937. He joined Humble Oil and Refining Co. in 1937 as a research engineer in the Production Research Division. He became assistant head of the Production Research Division in 1942 and retains the position today.

Both nominees are ably qualified for the chairmanship through a number of previous positions in the Petroleum Branch and AIME. The membership has a difficult choice between them, and the Branch will certainly go forward under either one that is chosen. ★ ★ ★

$50,000 Given to AIME Doherty Fund For Publications, Scholarships and Research

A gift of $50,000 has been made to the AIME by the Henry L. and Grace Doherty Charitable Foundation, Inc., to be placed in the AIME Henry L. Doherty Memorial Fund for the purpose of financing and printing publications, granting scholarships, and for research in matters relating to the petroleum industry. An additional $50,000 will be awarded the fund from three other sources to bring the principal amount of the fund to $100,000.

The Henry L. Doherty Memorial Fund was established in 1945. Since that time, the Cities Service Co. has contributed $5,000 annually to the fund, in lieu of income, in the memory of Henry L. Doherty. This money has been used primarily in publishing the annual volume, *Statistics of Oil and Gas Production and Development*, and the volume, *Petroleum Conservation*, published in 1951.

Mrs. Henry Lee Wessel, president of the Henry L. and Grace Doherty Charitable Foundation, made the gift in the form of Surface Combustion Corp. five per cent debenture bonds "as a contribution by this Foundation to the American Institute of Mining and Metallurgical Engineers."

Mrs. Wessel also stated: "It is our further understanding (that) you are contemplating that the income from the fund will be used to finance the printing and distribution of publications, to grant scholarships, and for research in matters relating to the petroleum industry, all, (to) the extent feasible, within fields and along lines in which the late Henry L. Doherty was known to be deeply interested."

The committee administering the fund consists of John M. Lovejoy, chairman, E. DeGolyer and Warren A. Sinsheimer. ★ ★ ★

Procedures Set Up for Branch to Execute Board Decision on Administration

Functional Petroleum Branch Created

The AIME Board of Directors has approved the principle of decentralization of appropriate administrative functions to the three Institute Branches. As a result, the Institute Local Sections which are predominantly Petroleum in membership will be established on a functional basis within the Petroleum Branch, to be administered through it. This will enable the Branch to become an integrated organization within the Institute, better able to serve the interests of the Petroleum membership.

The primary object of the Petroleum Branch office as originally established in 1946 was to serve the professional and technical interests of the membership through the handling of meetings and publications. Since that time, nine of the present 15 Local Sections, Chapters, and Sub-Sections have been founded. The tie between these petroleum units and the Branch office has grown steadily closer, but the Branch office has continued to serve only their professional function, while their administration has been handled primarily by the Institute headquarters in New York. This division has caused a cerain amount of confusion because the officers of the Sections and the Branch have sometimes been uninformed on the actions and wishes of each other.

The decision of the Executive Committee at its meeting in February to establish a Petroleum Section Conference was the first step toward alleviating this problem. The Conference will meet at the Petroleum Branch Fall meeting each October, and all Sections, Chapters, and Sub-Sections will send two representatives. The Conference will meet with the Branch officers to discuss Local Section and Petroleum Branch affairs and possibly make recommendations to the Executive Committee. In this way, the Conference will bring about a closer liaison between the local units and the Branch, and will effect a more functional organization. Individual members' suggestions on Branch and Institute affairs can be channeled through the Conference.

Changes in Adminstrative Procedures

The Board's recent decision makes possible a further big step toward the coordination of Petroleum interests. In the future, Local Section reports on meetings and activities, Section officers, finance reports, and requests for appropriations will be sent in duplicate to the Petroleum Branch office, which will forward one copy to New York and will make recommendations to the AIME Secretary and Board of Directors concerning these reports when it seems advisable. The New York office will continue to distribute direct to the Local Sections any refunds authorized by the Board to be paid out of the initiation fees. This refund is now 10 per cent of initiation fees.

There will be no change in the structure or operation of the Section Delegates Council, and the New York office will continue to reimburse delegates for travel expense. However, communications from the Section Delegates of the subject Local Sections which are intended for Institute headquarters will be sent in duplicate to the Petroleum Branch office. One copy will be forwarded to New York, and copies of all communications addressed to the delegates or to the Council by the New York office will be sent to the Petroleum Branch office.

Petroleum Branch Admissions Committee

Another result of the decentralization plan is the establishment of a Petroleum Auxiliary Admissions Committee seated in Dallas, which became effective Sept. 1. This committee, operating under the same principles as the Institute Committee, will receive all petroleum applications, process and forward them to the Institute Committee with recommendations for acceptance, refusal, or change of membership status. Because the Auxiliary Committee will consist of petroleum members centrally located in an area where a vast majority of petroleum applications originate, this committee will not only be of assistance to the Institute in questionable cases, but also will facilitate the final decision on applications through personal knowledge of the applicants' qualifications.

Members of the Auxiliary Committee for 1952-1953 include J. H. Sullivan, Atlantic Refining Co., chairman; T. S. Bacon, Lone Star Gas Co.; A. E. Caraway, Lufkin Foundry and Machine Co.; Frank C. Kelton, Core Laboratories; Tom E. Morton, Halliburton Oil Well Cementing Co.; and F. G. Prutzman, Sun Oil Co.

An additional activity of the Branch will be the re-organization of Petroleum Sub-Sections and Chapters into Local Sections where possible so that all Institute local units will operate on the same basis. The Branch will also coordinate Student Chapter activities in the same manner as Local Section activities.

The purpose of the Institute is service and benefit to its members, individually and collectively. Logically, this can best be achieved by the coordinated effort of individual members through the Branch, which is their specific interest unit, to the Institute. For this reason, the practical decentralization of administration to the Branches is a significant stride toward improving the Institute's operation. ★ ★ ★

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 408 Trinity Universal Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened and no fees are involved.

Replies to the positions coded Y5531, Y5532 and Y6654 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

PERSONNEL

♦ Executive assistant, 40 years old, 20 years' experience in the drilling, production, natural gas and construction phases of the oil industry in administrative and engineering capacities. Government service with Petroleum Administration for War. Desire supervisory or advisory assignment with progressive and well established oil or gas company. Presently employed with major gas transmission company. Preferable location, Houston. Code 168.

♦ Petroleum engineer with 16 years of excellent experience in production and drilling desires a change in employment. Location in Southwest preferred. Code 171.

♦ Petroleum engineer — seven years' experience in drilling, producing and well repairs, graduate engineer, presently employed by major company. Desire responsible position with smaller company. Code 172.

POSITIONS

♦ Graduate petroleum engineer with from two to five years' experience wanted for work on staff of large independent producer. Duties involve subsurface geology, development, production and reservoir engineering in California or Rocky Mountain area. Give references, details of education and experience in first letter, and enclose photograph. Code 543.

♦ Reservoir engineer, 25-40, with about five years' reservoir engineering experience. Location, Colombia, S.A. Y5531 (c).

♦ Engineers. (a) Petroleum engineer for field operations, 25-35, with degree in petroleum engineering or equivalent, and about three to five years' experience. (d) Junior engineers, recent petroleum engineering graduates, capable of developing under training. Location, Peru, S.A. Y5532.

♦ Engineers and designers, experienced, for design of blast furnaces, steel mills and oil refineries. Location, New Jersey, Ohio or Oklahoma. Y6654. ★ ★ ★

Personals

BRADLEY

CRICHTON

ROBERT J. BRADLEY and J. A. CRICHTON are partners in the new petroleum consulting firm of Bradley, Crichton and Associates, organized by the San Juan Oil Co. of Dallas. The new organization will maintain a staff of 12 professionally trained men, and will cover all phases of consultation and evaluation. Other members of the consulting staff are Virgil B. Harris, Mac D. Oliver, Bernard J. Esunas, Clyde C. Harter, Jr., Otis T. Griffin, R. Wayne Russell, Walter A. Tynes, H. Eugene Wright, W. Ray Staples and Kenneth C. English.

+

PAUL T. SEASHORE has been appointed first vice-president of the Louisiana Land and Exploration Co. Owen F. Thornton was named vice-president and Homer G. Moore was made assistant to the vice-president.

+

OTIS L. JAMES upon completing his work at the University of Texas in Austin has become associated with Gulf Oil Corp., geological department, at Fort Worth.

FREDERIC G. LAYMAN has taken a position as geologist with Stanolind Oil and Gas Co. in Scottsbluff, Neb., having received his master's degree in geology from Lehigh University.

+

ROBERT C. NEWMAN, for the past year a part-time instructor in the School of Petroleum Engineering at the University of Oklahoma, has resigned to continue work on his PhD degree.

+

HARRY C. FOWLER, chief of the fuels technology division of Region IV, Bureau of Mines, and superintendent of the Petroleum Experiment Station at Bartlesville, Okla., has been presented the Distinguished Service Award and Gold Medal of the Department of the Interior. The presentation was made during ceremonies held at Bartlesville on July 31. R. A. Cattell, chief of the Petroleum and Natural Gas Branch of the Bureau of Mines in Washington, D. C., presented the medal. Fowler has written or coauthored 19 technical articles pertaining to petroleum or natural gas. He has served with the USBM for the past 29 years, and has made notable technical contributions in the field of safety engineering.

W. H. GRIFFIN has been promoted to the newly created position of assistant to the sales manager of Welex Jet Services, Inc. He formerly was Gulf Coast Division manager for the company. In his new position, Griffin will participate in overall management problems throughout the entire Welex service area. He will maintain his headquarters in Houston.

+

E. S. NEAL has moved to Canada to take up his new assignment as general manager of the producing department, Imperial Oil, Ltd., in Toronto.

Directory to Appear With December Issue

Present plans are to issue the new AIME Directory free to members with the December issues of the Institute's journals. It will be a complete Directory, except for the material already published in the Directory supplement issued with the June issues of the journals, and the annual reports released last February and available in mimeographed form. That is, it will include the data previously published in the 1948 Directory on endowment funds, medals and awards, joint activities, constitution and bylaws, and necrology. The information on members will be based on the returned cards that were mailed to all members last spring, and unlike previous Directories will show the Divisional and Branch affiliations of members. The geographical section of the Directory will revert to the form used in the 1948 and previous Directories, rather than by companies, as in the 1950 volume. ★ ★ ★

Proposed for Membership, Petroleum Branch

Total AIME membership on May 31, 1952, was 17,772; in addition 2,413 Student Associates were enrolled.

ADMISSIONS COMMITTEE

T. D. Jones, Chairman; Thomas G. Moore, Vice-Chairman; Harold S. Bell, F. W. Hanson, R. H. Chadwick, T. W. Nelson, J. H. Scaff, John T. Sherman, A. C. Brinker, Ivan Given, C. A. R. Lambly, G. P. Lutjen, E. A. Prentis, and C. Leslie Rice, Jr.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

In the following list C/S means change of status; R, reinstatement; M, Member; J, Junior Member; A, Associate Member; S, Student Associate.

ILLINOIS

Flora — Harcourt, George K. (J).

KANSAS

McPherson — DeGeer, William D., Jr. (R, C/S-S-J).

LOUISIANA

Lafayette — Ward, William H. (J).

TEXAS

Abilene — Armstrong, Gerald T. (M).
Dallas — Davis, Sidney H. (J); Scott, J. O. (J).
Houston — Wainerdi, Richard E. (C/S-S-J).
Kingsville — Schnitz, Lewis B. (J).
Midland — Jones, Crandall D. (J).
San Antonio — Schimmel, Glen R., Jr. (R, C/S-S-J).

OKLAHOMA

Norman — Lane, Charles E. (J).

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Journal of Petroleum Technology

ADVANCE AIME MEETING CALENDAR

	1952	*1953*	*1954*
Petroleum Branch Fall Meeting (Mid-Continent)	Oct. 1-3, Rice Hotel, Houston	Oct. 7-9, Baker, Adolphus Hotels, Dallas	Not Determined
Petroleum Branch Fall Meeting (West Coast)	Oct. 23-24, Statler Hotel, Los Angeles	Oct. 22-23, Statler Hotel, Los Angeles	Not Determined
AIME Annual Meeting	———	Feb. 15-19, Statler Hotel, Los Angeles	Feb. 14-18, Statler Hotel, New York
AIME Fall Meeting	Sept. 3-6, Palmer House, Chicago	El Paso	———

AIME Representatives Appointed by Board

At the June 18th meeting of the Board of Directors appointments were made to important positions as follows: Oliver C. Ralston was appointed to succeed himself as AIME representative on the Division of Engineering and Industrial Research Council for a three-year term expiring July 1, 1955. Maxwell Gensamer was appointed as AIME representative on the Interim Board of Governors of the new publication *Acta Metallurgica* to be published next year and sponsored by the American Society for Metals in cooperation with several other societies. Michael L. Haider was appointed to succeed W. E. Wrather as AIME representative on the John Fritz Medal Board of Award of the four Founder Engineering Societies for a four-year term expiring Sept. 30, 1956. E. C. Meagher was appointed to succeed himself as AIME representative on United Engineering Trustees for a four-year term expiring October, 1956. R. M. Dickey accepted the appointment as AIME representative on the American Standards Association, Sectional Committee B30, Safety Code for Cranes, Derricks and Hoists. Stefan Boshkov was appointed to succeed W. H. Loerpabel, resigned, on the Technical Publications Committee, AIME, for the balance of the term expiring Oct. 15, 1952. ★ ★ ★

Anthony F. Lucas Medal To Be Given in 1953

An anonymous donor has provided sufficient funds to permit award of the Anthony F. Lucas Medal at the AIME Annual Meeting next February. The committee administering the Medal, Fred M. Nelson, chairman, has been especially authorized to proceed with the selection of a candidate even though the time for beginning its activities in this direction had passed before the funds for the award became available. The award is given for distinguished achievement in improving the technique and practice of finding and producing petroleum. ★ ★ ★

MIED Will Award Senior Scholarship

Decision has been made to have the executive committee of the Mineral Industry Education Division administer the AIME – Socony-Vacuum scholarship in petroleum engineering for the coming school year. The executive committee of the Division will adopt a permanent procedure for the administration of this and similar scholarships at its annual meeting in Los Angeles next February. Harry H. Power, Division Chairman, will ask schools having courses in petroleum engineering to submit the names of recommended candidates for the $750 scholarship as soon as possible. It will be open only to those who expect to complete their academic work in the 1952-53 school year. ★ ★ ★

50th Local Section Of AIME Accepted

An application from a group formerly known as the Adirondack Mining Club to become the Adirondack Local Section, AIME, was accepted at the June 18th meeting of the Board of Directors. This will be the fiftieth Local Section of the Institute. At the same meeting revised by-laws for the Wyoming Section were approved. Essentially the revised by-laws provided the integration of the petroleum and mining groups to the satisfaction of both groups. The Wyoming Petroleum Chapter will probably be absorbed by the Local Section. ★ ★ ★

Clarence D. Howe Receives Hoover Medal

Clarence D. Howe received the Hoover Medal for 1952 at the Centennial Luncheon in Chicago, Sept. 10. Howe, a native of Massachusetts and an MIT graduate, has distinguished himself in Canada as a civil engineer and as a key member of the Ottawa Government. The award is given by the Founder Engineering Societies jointly for distinguished public service by an engineer. ★ ★ ★

Pan American Group Invited to Los Angeles

The Pan American Institute of Mining Engineering and Geology (PAIMEG) is being especially invited to hold its Fourth Congress in Los Angeles at the time of the AIME Annual Meeting, Feb. 15-19, 1953. It is probable that PAIMEG's own program will immediately follow that of the AIME, with technical sessions on Friday, Feb. 20. ★ ★ ★

Necrology

E. W. K. Andrau (Member 1948) died on Oct. 20, 1951. Andrau was born in Sumatra, Dutch East Indies on Sept. 3, 1900. He attended schools in Holland and the University of Zurich. In 1925 he received the degree of Doctor of Science, Geology, from the University of Lausanne, Switzerland. For three years he was associated with the Iraq Petroleum Co. as geologist-general prospecting. In 1929 he became associated with the Shell Oil Co., St. Louis, and was engaged in special studies in Oklahoma and the Gulf Coast. In 1933 Andrau went to Germany and Roumania, working on special subsurface problems of D.E.I. He returned to open his office as consulting geologist and valuation engineer in Mexico oil fields. At the time of his death he was residing in Alief, Texas.

C. William Witt (Junior Member 1944) died recently. Born in 1918 at Fort Smith, Ark., he was graduated from the University of West Virginia in 1940. After graduation, he worked with The Texas Company in Salem, Ill., as a roustabout and later as petroleum engineer. During World War II he was an ensign with the USNR. Before his death, he was residing in Wichita, Kans.

Andrew Cyrus McLaughlin (Member 1919) died in January, 1952. He was born at Austin, Tex., in 1875, and was educated at the University of Texas, receiving a BS degree in 1896, and at Johns Hopkins University. He did geological survey work in several states before becoming associated with the Southwestern Oil Co. In 1919 he became vice-president and general manager of the Associated Oil Co. in San Francisco. In 1931 he became petroleum technologist for the Southern Pacific Co., in Los Angeles, Calif., where he resided at the time of his death.

Thomas J. Hamilton (Member 1940) died in October, 1951. Hamilton was born in 1896 at Fox Station, Indiana. He attended Columbus College at Bremen, Ohio. After graduation he joined the Empire Gas & Fuel Co. and in 1921 became associated with the Phillips Petroleum Co. He remained with this firm until 1940 when he joined the Mid-Continent Pump Supply Co. as sales manager. At the time of his death, he was residing at McPherson, Kan.

A. L. Weil (Member 1939) has died. Born on Jan. 8, 1876, Weil was a graduate of University of California, PhB and LLB. He had been president of the General Petroleum Corp. of California. ★ ★ ★

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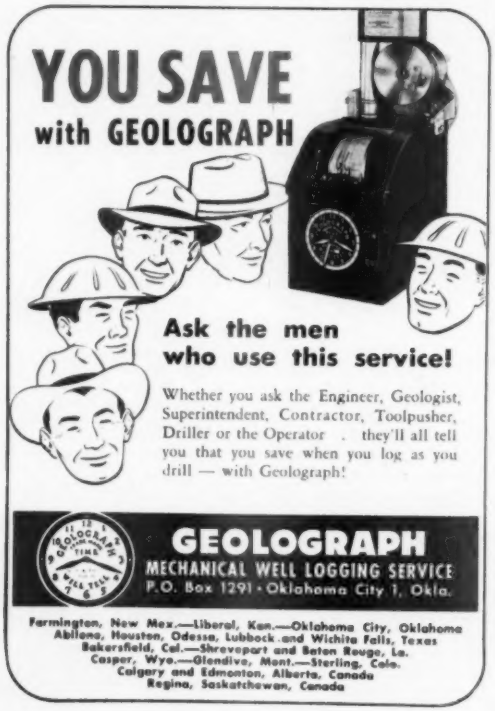
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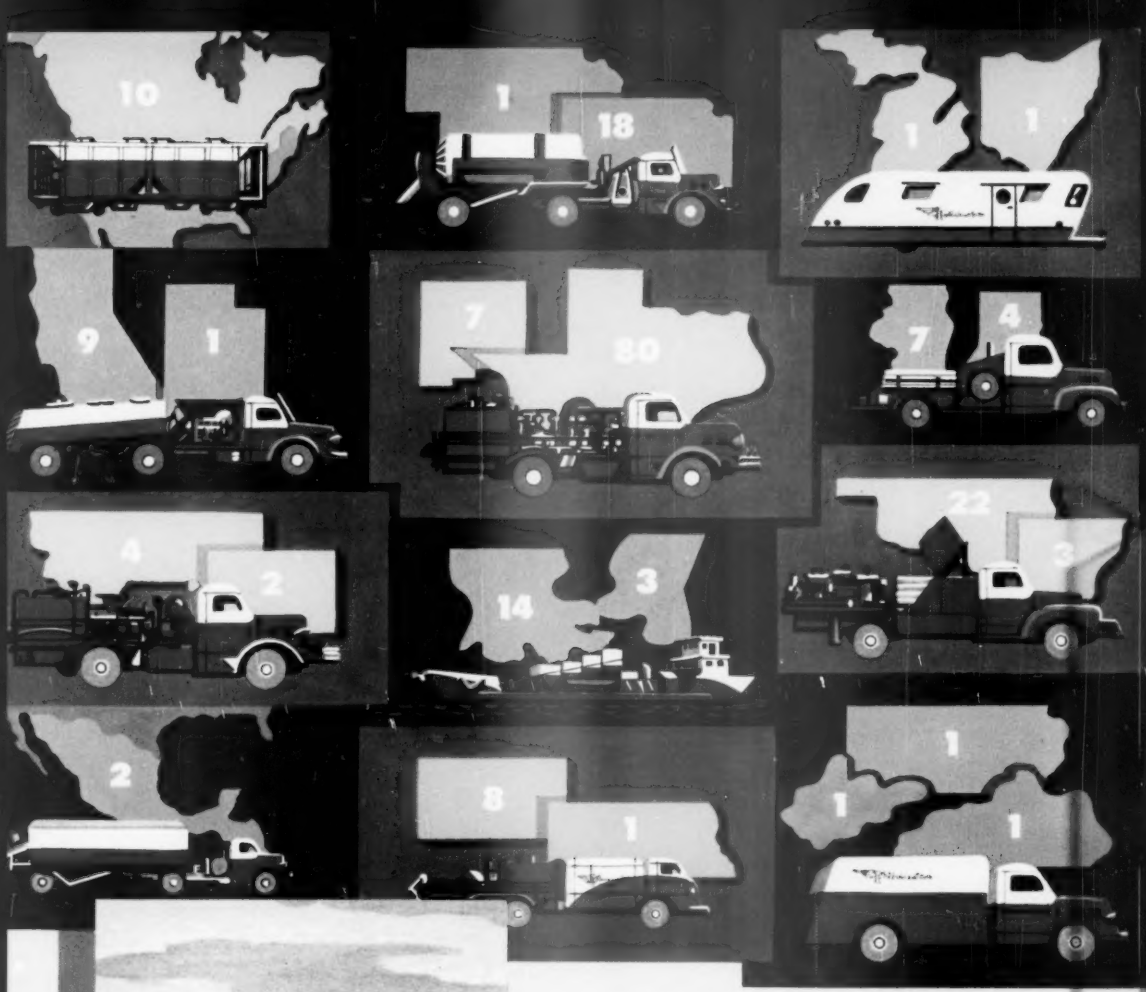

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